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TEST AND EVALUATION OF CHRYSLER T115 ELECTRIC VEHICLE

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ACCLAIM

The additional work undertaken by the Road Safety Directorate of Transport Canada is gratefully acknowledged as a significant study of on-road evaluation.

FINAL REPORT

TEST AND EVALUATION OF CHRYSLER T115 ELECTRIC VEHICLE

Prepared for:

Ontario Ministry of Industry, Trade and Technology

Ontario Ministry of Energy

Energy Mines and Resources Canada

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EXECUTIVE SUMMARY

The Ontario Centre for Automotive Parts Technology managed a program from 1983 to 1987 on behalf of the Provincial and Federal Governments to convert three Chrysler T115 vehicles to electric propulsion.

The design, development and conversion of the first unit was contracted to Brown, Boveri & Cie. in Germany. The conversion of the second and third vehicles was done by Powerplex Technologies Inc. in Downsview, Ontario.

The vehicles were equipped with Hagen lead acid batteries for most of the test program. Advanced prototype sodium sulphur batteries were installed in one vehicle during the final stages of the program.

The purpose of the program was to test the reliability, the performance and the commercial viability of an electric van operating in normal Canadian road and environmental conditions.

The vehicles were tested by the Ontario Ministry of Transportation and Communications (Downsview, Ontario) and Transport Canada in conjunction with Davis Engineering (Ottawa). The vehicles were tested in temperatures ranging from -5°C to 25°C.

MTC's tests assessed the reliability and acceptability of the vehicle in performing routine operations as well as measurements of power requirement and energy consumption. Transport Canada's tests evaluated the energy consumption and efficiency of the vehicle under different operating conditions. A comparison of the electric vehicle to a comparable internal combustion vehicle was also made.

The vehicle's performance achieved the expected results. Net energy consumption when compared to gasoline powered vehicles was very favourable. The program showed that the vehicle electrics and drive system are reliable, however the acceleration and maximum speed were limited by the voltage output of the lead acid battery.

The test results showed that the performance of the vehicle was not adversely affected by wide ranges in ambient temperature. This was due to the thermal management battery system in the vehicle.

The range (total distance travelled) of the vehicle was limited to 80 km due to the power output of the lead acid battery. When tested with the prototype sodium sulphur battery the range exceeded 200 km. With this range, market acceptance of this vehicle will be significantly enhanced.

The overall vehicle efficiency of the T115 electric van was calculated to be 58%. This compared very favourably to the gasoline powered vehicle which has an efficiency of approximately 17%.

Results of this program confirmed the fact that until suitable advanced batteries are available, commercial applications of electric vehicles will be limited. With the development of the sodium sulphur battery by Powerplex Technologies, the needed breakthrough appears to be within reach to overcome the key technological impediment to the promotion and use of electric vehicles for on-road commercial applications.

Investigation of near term battery systems showed that the most viable batteries to power electric vehicles are the sodium sulphur and the nickel iron batteries. The cost of nickel however is seen as a major disadvantage of the nickel-iron battery. The sodium sulphur batteries are presently being produced in limited quantities by Powerplex Technologies.

The future development of electric vehicles in Ontario will have to be closely tied in with the developments at Powerplex Technologies. The Chrysler T115 vehicles should be used to test and evaluate these batteries. This can be considered as an Ontario contribution towards the continued development of electric vehicles. There are other promising new batteries in Canada, however they are not available for testing in vehicles at this time.

These vehicles can also be used as test beds for other new battery systems as they are developed. The vehicle's electrics will require modifications. However, these are not seen to be insurmountable obstacles.

The mechanical components of the Chrysler vehicle should also be modified to improve the performance of the electric propulsion system.

This program has resulted in significant opportunities for Ontario in the development of electric vehicle and battery technology. As a result, Ontario is recognized as a leader in the electric vehicle industry and the choice of the next international conference on electric propulsion in 1988. The achievements of the last four years should be continued and new programs developed to address the needed shortcomings in order to further the lead established by Ontario in the electric vehicle industry.

ABSTRACT

Three Chrysler T115 mini vans were converted to electric drive in the Spring of 1984. Brown, Boverie & Cie. (Heidelberg, W. Germany) was contracted to design, develop and install the electric components for one unit and supply the necessary parts to have the remaining two units converted in Ontario. A second contract was awarded to Powerplex Technologies Inc. to convert and maintain these units. The electric van was tested by the Ministry of Transportation and Communications (Ontario), and Transport Canada, in conjunction with Davis Engineering, in Ottawa. The van was tested in test track, chassis dynamometer, and urban road settings. Vehicle D.C. energy consumption and driving range were measured on the SAE J227a C schedule driving cycle, and at constant speed at the Blainville, Quebec test track. Other tests measured top speed, maximum acceleration, hill climbing, and braking performance of the vehicle. This report presents test results, data on vehicle operating characteristics, and description of vehicle electric components.

Funding for this project was provided equally by the Provincial Government (Ministry of Energy through Ministry of Industry, Trade and Technology) and the Federal Government (Department of Energy, Mines and Resources). Ownership of the vehicles and the responsibility for maintenance belong to the Ontario Centre for Automotive Parts Technology.

The report discusses the program and objectives of the project. In Section 2, the background and objectives are discussed, followed by a brief description of the program in Section 3. In Section 4, the procedure for the design, development and conversion of the three vans is presented.

The test programs presented by MTC and Transport Canada are outlined in Section 5, followed by an analysis and comparison of the test results in Section 6.

Section 7 presents a summary of current battery technology. The discussion covers battery systems that are expected to be available before 1990 and those that are not expected to be available until after 1990. (See References and Sources).

In Section 8, a comparison of the vehicle powered by lead acid and sodium sulphur is presented and the test results analyzed.

In Sections 9 and 10, conclusion and recommendations are presented based on the results and present economic conditions.

The battery system used to evaluate the T115 electric vehicle was mainly the lead acid battery since the sodium sulphur battery was not available until the latter part of the project.

The B06 sodium sulphur battery used in EV03 was a prototype battery supplied by BBC from Germany. Data obtained from this test should be used cautiously since it is based only on one complete test cycle.

SUMMARY OF CHARACTERISTICS AND TEST DATA

	EV02[1] Lead Acid	EV03[2] BO6 NaS
Vehicle curb weight	1795 kg	1880 kg
Gross vehicle weight	2050 kg	2050 kg
Vehicle pay load	255 kg	170 kg
Battery pack	108 V	112 V
	143 Ah	250 Ah
Traction Motor, DC separately excited		
rated output, 2100 rpm	15 kW	15 kW
15 min.	17 kW	17 kW
5 min.	25 kW	25 kW
1 min.	30 kW	30 kW
maximum torque	130 Nm	130 Nm
Armature controller, thyristor chopper		
maximum armature current	320 A	320 A
rated armature current	162 A	162 A
Field controller, transistor chopper		
currrent	0-6 A	0-6 A
DC-DC converter	700 W	700 W
On-board charger	2.2 kVA	2.2 kVA
Maximum speed ever reached	92 km/hr	92 km/hr
Constant speed 56 km/hr best range	81 km	209 km
SAE J227a C cycle best range	35 km	85 km
Acceleration time 0 to 50 km/hr	16 sec	16 sec
Acceleration time 0 to 50 km/hr with battery 80% discharged	58 sec	17.2 sec
Best gradeability at 50 km/hr speed with second gear	6 %	6 %
Top speed on 10% grade	30 km/hr	30 km/hr
Best braking distance from 50 km/hr on dry pavement	22 m	N/A
Best braking time from 50 km/hr on dry pavement	4 sec	N/A
Best braking distance from 50 km/hr on wet pavement with estimated friction coefficient 0.2 - 0.3	36 m	N/A
Vehicle energy consumption at 56 km/hr constant speed	144 Wh/km	157 Wh/km
Vehicle energy consumption per SAE J227a C cycle driving	136 Wh/cycle	138 Wh/cycle
	237 Wh/km	236 Wh/km

[1] EV02 is the vehicle equipped with lead acid battery system.
[2] EV03 is the vehicle equipped with sodium sulphur battery system.

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2. INTRODUCTION

2.1 Background and Objectives

In 1982, under the chairmanship of the Ministry of Industry and Trade, the Ministry of Energy funded the Electric Vehicle Task Force to report on the markets and industrial applications of developing electric vehicles in Ontario. In addition to the Ontario Ministries of Energy and Transportation and Communications, the Task Force included representatives of several federal departments, two municipalities, and a number of private sector firms and associations.

The Task Force report which was published in July 1982, addressed the following:

- reviewed the performance and cost attributes of a substantial number of existing electric vehicles
- reviewed existing and projected performance and cost attributes of some 12 battery types
- identified nine market segments with high suitability for electric vehicle application
- prepared economic comparisons and market estimates for electric vehicles within each of the nine segments
- assessed the industrial/economic implications of an electric vehicle industry in Ontario based on the above projected volumes, and,
- made recommendations for a program to develop and test an electric van in conjunction with one or more private sector firms

The Task Force considered and assessed a number of possible industry/government initiatives and melded these into two options. Option I: Targeted Development, Application Engineering and Demonstration, represented a moderate increase in the level of industry/government activity; Option II: A Support Program for Electric Vehicle Components/Vehicle Production and Marketing, represented a more aggressive approach. A phased approach was proposed under which the moderately increased level of activity would be carried out for a period of three years followed by a review of results; depending upon results and related developments at that time; the initiatives would be stepped up to an increased level (Option II), would be continued at the moderate level (Option I), or might be scaled back to existing or lower levels.

As a key element of Option I, the Task Force report recommended a jointly financed system design whereby a full scale prototype electric vehicle system would be produced. At that time, a light service van was considered to be a suitable configuration to undergo a limited program of testing and evaluation in service fleets.

2.2 Purpose of Program

Based on these recommendations, a program was proposed by the Ministry of Industry and Trade to develop an electric drive and control system matched to a North American van and to evaluate the performance of this vehicle operating in a duty cycle representative of normal Canadian road and environmental conditions. The developed van was to be powered with advanced batteries such as sodium sulphur. However, until advanced batteries could be made available, lead acid batteries would be used to confirm the reliability of the electric van.

2.3 Methodology

In March 1983, an agreement was reached whereby the Ontario Centre for Automotive Parts Technology (OCAPT) agreed to act as program manager to carry out an electric vehicle demonstration program on behalf of the Ontario Provincial Government (represented by the Ministry of Industry and Trade and Ministry of Energy) and the Federal Government (represented by Energy, Mines and Resources). The funding for the program was divided equally between the provincial and federal governments. The objectives of the three government Ministries involved varied.

The Ministry of Industry and Trade's objective was to test the commercial viability of an electric vehicle with the longer term objective of establishing an electric vehicle industry in Ontario.

The Ministry of Energy's objective was to establish the Chrysler T115 electric vehicle as a test bed for future advanced battery development testing.

The Department of Energy, Mines and Resources' objective was to determine energy consumption and efficiency of an electric vehicle.

OCAPT, as program manager, developed a program which addressed all the above objectives.

The program included:

1. Contracting the system engineering design to Brown, Boveri & Cie., Heidelberg, W. Germany (BBC), to convert one Chrysler T115 mini van to electric propulsion.

2. Converting two additional Chrysler vans in Ontario to electric propulsion using components supplied by BBC.

3. Arranging vehicle testing and evaluation.

4. Reporting on results

2.4 Rationale

Chrysler T115 Van

The Chrysler T115 mini van was selected by the Task Force for the prototype conversion because:

a) The vehicle is of proven design with maintenance expertise and replacement parts available throughout North America, and,

b) The T115 is manufactured in Ontario and can be configured as a light commercial vehicle, passenger car, or small bus.

Brown, Boveri & Cie. (BBC)

The design and manufacture of the electric motor and control systems and their adaptation to the T115 was to be carried out by one contractor with a proven track record to avoid division of responsibility for achieving the project objectives. BBC was chosen by the Ministry of Industry and Trade as the contractor for a number of reasons:-

a) It is a multi-national company with a world-wide presence, including Canada.

b) It has a deep commitment to electric vehicles with many years of experience in electric vehicle system development, i.e. motors and controllers.

c) It has extensive R&D commitment to the development of a NaS battery (60% of money from BBC; 40% of money from the government of the Federal Republic of Germany).

Brown, Boveri & Cie. (BBC) (cont'd)

d) Choosing BBC enables us to tap what is probably one of the best sources of electric vehicle power system and battery development in the world, without any Canadian contribution to the R&D program. The project cost is to adapt the system to the Canadian vehicle.

e) BBC have stated that if commercial viability exists in North America, they would only exploit it through manufacture in North America by BBC or by a joint venture with another company.

3. PROGRAM DESCRIPTION

On December 2, 1983 a contract was signed with Brown, Boveri & Cie. to design, develop and install an electric power-train system, and the necessary parts and components, in a Chrysler T115 mini van. The vehicle was to be powered by an advanced lead acid battery until such time as the new sodium sulphur battery was available.

An Electric Vehicle Steering Committee was formed to review the progress and findings of the program. Membership in this committee was chosen from OCAPT, (M. Melconian, Chairman); M.I.T., (W. Ledingham); M.O.E., (N. White); E.M.R., (G. Maund); and Transport Canada, (J. Morgan). The membership was later expanded to include M.T.C., (A. Stermac).

On February 24, 1984, one T115 mini van (8 passenger wagon) was delivered to BBC in Heidelberg, Germany. Prior to that, a four speed transaxle and an instrument cluster were shipped to BBC in order for the design to get underway as soon as possible.

BBC promptly sent back some preliminary calculations and projections on the expected characteristics based on the vehicle data sent to them by Chrysler and the extra parts (transaxle) sent by OCAPT.

These showed that such a vehicle would be expected to perform as follows:

Range at 70 km/hr	-	$\geq$ 55 km
Acceleration 0-50 km/hr	-	16.3 s
Gradeability	-	$\geq$ 25%
Maximum speed	-	95 km/hr
Payload w/o driver	-	210 kg

These characteristics were to be obtained using a 14 kw (18.8 H.P.) motor with rated voltage of 105V, and a 108V lead acid battery with capacity rated at 143 Ah.

The design and development of the electric propulsion system was interrupted due to the labour strike in Germany which paralyzed all manufacturing operations for 7 months. The van was completed, in early December 1984, and put into operation in Germany. During the first week of testing, the four speed transmission failed and a new one had to be sent. The converted, tested and approved van was received by OCAPT in Toronto in the middle of March and was delivered to Powerplex/Magna on March 23, 1985.

4. CONVERSION PROCEDURE

While BBC were developing the electric drive system, the E.V. Steering Committee began to plan for the conversion and testing phases for these vehicles. Two T115 vans were ordered by the end of March and delivered in September 1984.

In June 1984, 12 Ontario companies were identified as possible candidates to do the conversion of the two vans to electric drive. Expression of Interest letters were sent to each describing the program and asking them if they were interested in participating. The list included: Ontario Bus Industries; Powerplex/Magna; Stegor Consultants; DSMA Atcon; Flight Systems Ltd.; Ontario Drive and Gear; Lansing Bagnall Ltd.; Lucas Industries; Massey-Ferguson; Dominion Auto Accessories; Wells Corporation; and Girardin Vehicles Industries.

The first five expressed interest and members of the committee visited each to discuss the program in detail, as well as evaluate the respondents' capabilities to not only accomplish the initial two conversions but also to see if they had the capability of large scale conversion and the service required if and when the demand developed.

The list of participants reduced to four and on August 31, 1984 OCAPT send each a formal Request for Proposal to convert the two T115 vehicles as well as indicate their plan for future large scale conversion.

Each response was evaluated by the committee and it was decided to approach Powerplex Technologies Inc. to negotiate an agreement. An agreement was signed December 2, 1983.

Soon after the delivery of the prototype van from Germany, (EV01), the additional components were shipped and conversion of the two vans was underway.

Features of the converted van include the following:

: Regenerative braking
: Variable charge rate
: Compact, lightweight "smart" charger
: Built-in electronic diagnostic system
: Quick, single point battery watering system
: Battery thermal management for cold weather operation
: Two hydrogen ventilation systems
: Convenient charging cord with reel
: Interior heating control with programmable timer
: Over temperature protection for motor, controller and battery
: Motor overspeed protection
: Battery overvoltage protection and deep discharge protection
: High charging speed short circuit protection
: Main power interlock:

The vehicle will start only when: -

- the power cord is unplugged and retracted
- the vehicle is stopped
- the ventilation and cooling fan is operational
- the correct battery voltage is available
- the driving system is operational
- the acceleration pedal is not depressed

On BBC's recommendation, the committee agreed to equip all three vehicles with the Hagen lead acid batteries which were considered by BBC to have proven realiability in this application. The committee felt that equipping all three vehicles with the same battery would be an asset, especially for testing purposes.

The Hagen battery pack weighs 550 kg complete with electric cables and thermal management system. It includes eighteen 6-volt battery modules connected in series and provides 143 Ah capacity. The battery pack is located over the rear axle inside the vehicle.

Battery Charging

The battery charger, housed inside the controller box, has two charging rates with outlet demands of 2 kW and 2.9 kW. The slow (2 kW) charge rate is recommended by the battery manufacturer (Hagen).

The battery charger has four electronically controlled stages. Initially, the charger puts out a constant power, with a charging current around 16 A. The duration of the first stage depends on the stage of discharge of the battery. The transition from the first stage to the second stage takes about 20 min. The charge current gradually decreases to 4 A, and maintains this level for about 1 hour. The third stage includes off and on periods with changing cycles. The off-period is about 30 min and the on-period is about 18 min with a charging current at about 4 A. This stage ends at the end of the 8th cycle. The battery pack is fully charged at the end of the third stage. Recharge from a full discharge takes approximately 8 hours.

If the battery-charger plug is left plugged-in at the end of the third stage, the fourth stage will start. The fourth stage repeats in about every 6 hours. This stage consists of an off-period which lasts about 5 hours and an on-period which lasts about 45 min. The on-period consists of an inrush current with an approximate eight ampere peak current, which diminishes to zero in about 35 min. It is then followed by an approximate 4 A charging for about 15 min. The fourth stage will repeat as long as the charger plug is plugged in.

Motor

The motor is a modified version of the BBC electric motor used on the Volkswagon electric car. It has a rated power of 14 kW (18.8 H.P.), and weighs approximately 90 kg with maximum efficiency rated at 87%.

Transmission

The transmission is a standard 4 speed Chrysler transmission. From the outset, it was recognized that this transmission is not well suited for electric vehicle application (nor the automatic transmission available through Chrysler). Nevertheless, it was used to expedite the project. The original motor and transaxle mounting points have been utilized with modified mounting brackets. The motor shaft has been keyed to a steel flange which bolts directly to the flywheel.

The first converted vehicle by Powerplex (EV02) was completed and delivered to the Ministry of Transportation and Communications on June 17, 1985.

The second vehicle (EV03) encountered problems with the controller which delayed the conversion. Realizing that a prototype sodium sulphur battery was going to be available before the end of the year, 1985, the decision was made to prepare the vehicle for the conversion to accept the more advanced B06 sodium sulphur batteries.

The conversion of the second vehicle (EV03) to sodium sulphur batteries was completed and delivered to MTC for testing on April 4th, 1986.

The committee decided to use the original BBC converted vehicle (EV01) as a demonstration vehicle to be displayed in exhibitions and shown to interested parties. The second and third vehicles (EV02 AND EV03) were to be used for dynamometer and track testing.

Testing of the lead acid battery vehicle, performed by MTC and Transport Canada, was done on EV02.

The sodium sulphur battery vehicle (EV03) was tested by MTC only. The results are based on one complete test cycle. After the completion of the one cycle, one of the two batteries failed due to faulty welding at the bottom of one of the cell casings. This casing design has since been modified by Powerplex Technologies.

5. TEST PROGRAM AND PROCEDURE

After reviewing various facilities in Ontario, the committee accepted a proposal by the Ministry of Transportation and Communications to test the T115 electric vehicle. The program and facilities were reviewed by the committee resulting in an agreement. The scope of testing was defined (Appendix I) and testing began on June 24, 1985.

Additionally, Transport Canada expressed an interest in the vehicle and offered the use of a sophisticated data acquisition system to measure the energy consumption and efficiency of the Chrysler T115 electric van (Appendix II) in Ottawa, Ontario.

Furthermore, Davis Engineering Ltd. was contracted to conduct a constant speed range test at the Motor Vehicle Test Centre in Blainville, Quebec using the low speed test track.

Recognizing that the more advanced NaS batteries from BBC were forthcoming, and that the lead acid battery was used in the interim, battery performance was not an issue in the test program.

Detailed description of each program follows:-

5.1 MTC Program

The objective of MTC's program was to test two T115 Chrysler vehicles under Canadian seasonal conditions to assess their reliability and acceptability in performing routine operations in commercial service. In addition, power requirements and energy consumption were to be measured.

Vehicle inspection was the first step in MTC's program. This was done at MTC Downsview initially and more thoroughly at the Centralia test facility near London, Ontario. The vehicle, EV02, was transported from Downsview by flat-bed trailer. The inspection results are recorded on the vehicle check sheet and presented in Table 5.1, Vehicle Check List (see Appendix III).

Vehicle operation check was done based on the vehicle operation and handling check list presented in Table 5.2, Appendix III.

General Test Procedure

Vehicle Preparation

Prior to a test, the battery pack was conditioned for three consecutive days by a deep discharge and charge cycle. This also applied to tests carried out on Mondays.

At the start of a test, the battery pack was fully charged and topped-up with demineralized water. The vehicle was also kept at room temperature (20-25°C) for a minimum of eight hours prior to the test. Because the vehicle was plugged to the ac power outlet, the battery pack was always under the control of the thermal management system of the vehicle. Consequently the battery pack temperature was always close to its desired operating temperature before it was driven to the test site. The vehicle tire pressure was checked and adjusted to 45 psi when tested on the dynamometer, and to 35 psi for other applications. The gross vehicle weight was adjusted to its rated GVW, i.e., 2050 kg, as closely as possible. All the windows were closed when the vehicle was tested on the road.

Acceleration, Braking and Gradeability Tests

Data for vehicle acceleration, maximum speed and braking were obtained from tests conducted for power requirements for 80 km/hr at New Lowell.

Gradeability was calculated using analytical methods. The data was derived from the speed vs time curve, which was recorded from the power requirements tests.

Power Requirements for Constant Speed

Track testing was initially attempted at Centralia, but due to track conditions, an alternate site was chosen. Track testing was conducted at New Lowell, just North of Toronto.

Constant speed readings of the motor and battery currents were recorded, as well as the battery voltage. Readings were recorded at approximately 20 km/hr intervals.

On-Road Testing

To determine reliability and road worthiness of the vehicle, the van was driven through a simulated delivery route in the Metropolitan Toronto area within the range of the vehicle. The service route followed is shown in Figure 6.2c, Appendix IV.

Dynamometer Setting

The settings for the dynamometer were obtained from the on-road power requirements for 80 km/hr constant speed test carried out at New Lowell, just north of Toronto.

The total dynamometer power was set to 8.206 kW (11 HP) and the equivalent moment of inertia was set to 2042 kgs (4500 lbs). Prior to the test, the dynamometer was warmed up and a typical coastdown test procedure followed. The test started only if the coastdown test was successful.

Criteria for Test Termination

1. SAE J227a C Cycle Test: testing would be terminated when the last cycle acceleration time, from 0 to 48 km/hr, exceeded 20 seconds. That cycle would also be counted as a completed cycle.

The range of the C cycle test is based on the trip odometer reading multiplied by a correction factor of 1.022.

2. Constant Speed Range Test: testing would be terminated when the vehicle speed falls below 95% of the specified constant speed (56 km/hr).

3. System Failure: testing would be terminated or cancelled if either the vehicle system or dynamometer failed. Under these conditions, the test would be abandoned and results discarded.

Cold Temperature Test (-15°C)

To perform the cold temperature testing, the vehicle was stored inside MTC's vehicle conditioning chamber where temperature was set at -15°C. The vehicle was stored and plugged to the ac power outlet for a minimum of 20 hours prior to the test. The dynamometer room heating system was also shut off the night before the test.

When the dynamometer was set for the test, the vehicle was unplugged and driven from the conditioning chamber to the dynamometer which was only thirty feet away.

Test Instrumentation

The instrumentation used by MTC during the testing and evaluation of the electric vehicle is listed in Appendix IV.

5.2 Transport Canada Program

The objective of TC's program was to determine the energy consumption and efficiency of the electric vehicle under different operating conditions.

The Traffic Safety Standards and Research Branch of Transport Canada (TC), in association with Davis Engineering Ltd. (D.E.) submitted the following program of measurements and analyses to determine the energy consumption and efficiency of the T115 electric vehicle under typical operating conditions.

General Test Procedure
Vehicle Maintenance

A complete maintenance and operational check was performed on the vehicle prior to testing similar to the MTC vehicle inspection and check list. The emphasis was placed on the condition of vehicle drive train components that could affect the road load of the vehicle (i.e. tires, brakes, wheel bearings, and wheel alignment).

During the testing program the vehicle was generally driven on a daily or bi-daily basis to ensure that the batteries were properly cycled.

Test Procedure

Prior to performing a testing sequence the vehicle battery pack was fully charged and topped-up with demineralized water. The tire pressures were checked and adjusted. The operation of the vehicle drive system was checked and the proper operation of the data acquisition system was assured. To maintain similar conditions, all testing was performed with windows closed and other controls turned off. Headlights were turned on during all road testing.

On Road Testing - Typical Operation

On road testing was performed using four sections of the city as described in Appendix IIa. In order to minimize the effect of uncontrollable variables, testing was done when:

- road surface was clear and dry
- wind speed did not exceeed 40 km/hr, and,
- off peak traffic conditions

On Road Testing - Steady State

Constant speed tests were performed at approximately 20 km/hr intervals. An attempt was made to test the vehicle at maximum speed but this was not possible due to the fact that the vehicle was only capable of maintaining speeds of greater than 80 km/hr for short periods of time. Constant speed range tests were also performed on the vehicle at a speed of 56 km/hr.

Energy Consumption Test

Energy consumption measurement tests were performed on straight level section of Eagleson Road, south-west of Ottawa, between Regional Roads 10 and 12. The test section is a relatively new asphalt surface which is straight and smooth and has an average grade of .09%.

Prior to testing, the vehicle was towed for 30 minutes at 80 km/hr to pre-condition the drivetrain components. A test sequence at each speed included three runs in each direction of the track for a minimum of 60 seconds.

Constant Speed Range Test

The constant speed range tests were performed at the Motor Vehicle Test Centre in Blainville, Quebec, using their low speed track facilities. The

test track is a 6.9 km oval with flat curved sections. The track surface is asphalt.

The testing was performed three times as per the Tennessee Valley Authority Procedure.

Dynamometer Test

Dynamometer testing was performed on the electric chassis dynamometer at the Department of Environment, River Road Laboratory, River Road, Ottawa. Testing was conducted in accordance with SAE Recommended Practice J227a "Electric Vehicle Test Procedure". Specifically the test cycle defined by Schedule C was the cycle used throughout the test (Fig. 6.2h). Each test run consisted of thirty-five (35) cycles, each 80 seconds duration. Cruise speed (48 $\pm$ 1.5 km/hr) was maintained for 20 seconds.

Test Instrumentation

The instrumentation used by Davis Engineering during the testing and evaluation of the electric vehicle is listed in Appendix V.

6. PERFORMANCE RESULTS AND ANALYSIS

6.1 Vehicle Tractive Energy Demand

The vehicle tractive energy demand, or alternatively the mechanical energy consumed or generated at the driverwheels, was evaluated by Davis Engineering using:

a) A computerized method based on the vehicle mass, actual speed, coefficients of drag and rolling resistance and the elevation profile. The estimated road load power vs speed is shown in Figure 6.1a. Figure 6.1b shows the estimated road load power as a function of time for a typical operation test.

The average estimated tractive energy demand was calculated to be 1328 kJ during consumption and 391 kJ during regeneration (see Table 6.1).

b) Vehicle power requirements based on wheel torque and speed were measured during one of the on-road typical operation testing sequences. The measured road load power for a typical operation is shown in Figure 6.1b as a function of time along with the estimated road load.

The average measured tractive energy was 1303.5 kJ during consumption and 524.7 kJ during regeneration (see Table 6.1).

6.2 Vehicle Energy Consumption

Vehicle energy consumption, based on battery voltage and current over time, was measured by DAVIS and MTC during tests at constant speed (steady state), tests during various on-road trips and over a standard SAE J227a C schedule.

6.2.a Constant Speed (Steady State)

DAVIS

Constant speed tests were performed at speeds of 20, 40, 60, and 80 km/hr. Tests were performed on a straight level section of Eagleson Road, as previously stated in Section 5.2.

A test sequence at each speed included three runs in each direction of the track for a minimum of 60 seconds. The results of each speed were then averaged (Table 6.2a).

MTC

Track testing was done on a 1.7 km straight and reasonably flat section of the Simcoe County Highway 9 at New Lowell north of Toronto. The vehicle was transported from Downsview to New Lowell and back on a flat-bed trailer. Readings were recorded at approximately 20 km/hr intervals.

The power requirement tests at constant speeds were conducted before and after the front wheel alignment had been corrected. The results are provided in Table 6.2b. Test sequence at each speed also included a minimum of three runs in each direction. Wind speed during testing was less than 16 km/hr, which minimizes its affect on the average energy consumption.

Comparison of Results

The results of the tests by both agencies are plotted in Figure 6.2a. In all cases, the MTC results indicate lower energy consumption at a given reference speed. The difference is approximately 100 kJ/km.

The consistently lower energy consumption during the MTC test are probably due to the ambient temperature during the testing. Without exception, all of the DAVIS short term steady state tests were conducted when the

temperature was below 0°C (i.e. -1 to -4°C). The MTC results were obtained at test temperatures above 20°C (i.e. 21 to 25°C).

Tires will consume more energy at cold temperatures than at warm temperatures. As the vehicle speed increases rolling resistance becomes a smaller percentage of the total energy consumption. Aerodynamic losses will be greater at low temperatures due to the effect of temperature on air density.

During the DAVIS on-road tests, the following speeds were used to determine the appropriate gear:

1	2	3	4
0 - 40 km/hr	40 - 60 km/hr	+60 km/hr	N/A

In comparison, the MTC tests were based on gear selections at the following speeds:

1	2	3	4
0 - 30 km/hr	30 - 48 km/hr	48 - 75 km/hr	+75 km/hr

Other reasons for the differences in the test results include the condition of the road surface, the wind conditions and the barometric pressure. It is not possible to accurately determine the difference in roughness of the two road surfaces (New Lowell vs Eagleson Road) and determine the effect that the difference would have on energy consumption.

6.2.b On Road Typical Operation Tests

Energy consumption was calculated for the DAVIS "typical operation" test runs and the MTC "urban driving" cycles.

DAVIS

Electric vehicle energy, based on current and battery voltage was evaluated during the on-road tests over the defined test segments. The road segments are shown in Figure 6.2b. Results are provided in Table 6.2c.

MTC

The MTC "urban driving" test runs were conducted on roads in the Metropolitan Toronto area within the vehicle range. The road segments are shown in Figure 6.2c.

Two return trips were made between the East building in the MTC complex, and the Queen's Park government garage on Bay Street, via two different routes (Table 6.2d). Only one of the two routes provided the data necessary to correlate the energy consumption with the average trip speed (Route 2). During that test, 8.84 kw-hr d.c. energy was consumed over 31.1 km (1023 kJ/km). The average trip speed was 26.3 km/hr.

Comparison of Results

The results illustrate that although the consumption is sensitive to average velocity, it is dictated to a greater degree by the type of route on which the vehicle is being operated.

Plots of speed and battery power vs time for Section 1 through 4 are provided in Figure 6.2d to 6.2g. Figure 6.2e illustrates that Section 2, which consistently had the highest energy consumption, required a significant number of accelerations from zero to speeds in excess of 50 km/hr. In contrast,

Section 4, which has a low consumption associated with high average velocity, is run at a constant speed of approximately 80 km/hr.

Due to the variability of the on-road testing, with respect to the number of stops and starts, the road surface, and the geometry of the test segments, it is difficult to draw meaningful conclusions regarding a comparison of the two sets of test results.

6.2.c Dynamometer Testing (SAE J227a - Schedule C)

Testing was conducted in accordance with SAE Recommended Practice J227a "Electric Vehicle Test Procedure". Specifically; the test cycle defined by Schedule C was used throughout test.

SAE J227a C Cycle

The fully charged test vehicle is driven according to the SAE J227a cycle driving pattern (Figure 6.2h[1]). The velocity/time profile used is the JPL interpretation of the SAE J227a C Schedule. This involves accelerating to 48 km/hr in 18 seconds, cruising at 48 km/hr for 20 seconds, coasting for 8 seconds, braking for 9 seconds and idling for 25 seconds for a total of 80 seconds per cycle. This is repeated until either the vehicle is unable to meet the acceleration requirement or the battery voltage falls below the manufacturer's recommended cutoff voltage during the cruise portion of the cycle. When either of these criteria is met, the test is ended and the distance travelled through the last full cycle and the number of full cycles completed are recorded. This test is performed at least twice with additional runs being made if the spread of the data is greater than 20 percent.

[1] The velocity/time profile used, is the Jet Propulsion Laboratories interpretation of the SAE J227a C schedule.

Dynamometer testing was performed on the electric chassis dynamometer at the Department of Environment (DOE), River Road Laboratory, River Road, Ottawa.

In order to ensure uniform testing the shift points were defined and the test driver was guided by the Driver's Aid recorder. Each test run consisted of thirty-five (35) cycles, each 80 seconds duration. The duration of the test was determined by the DAS storage capacity. Cruise speed (48 + 1.5 km/hr) was maintained for 20 seconds, during each cycle. Table 6.2e provides a summary of the dynamometer parameters. Table 6.2f provides a summary of the results.

MTC

The dynamometer test parameters are provided in Table 6.2g. MTC testing was terminated when the vehicle, which could normally accelerate from 0 to 48 km/hr in 18 seconds, could not achieve that speed in 20 seconds (Table 6.2h).

Comparison

The net energy consumption, which was calculated from the MTC results, was considerably higher than the similar value, which was recorded during the DAVIS tests (975 kJ/km vs 720 kJ/km respectively). It is speculated that the difference in results was due to:

a) The lower inertia weight which was used by DAVIS (1991 kg vs 2042 kg). This difference will result in less energy being consumed when the vehicle is accelerating. Although more energy will be regenerated during deceleration when a higher inertia weight is used; the final effect will be a decrease in net energy consumption.

b) The use, by MTC, of a Clayton mechanical dynamometer. The Clayton dynamometer provides control of only one factor in the road load equation. When setting up the dynamometer it is based on the road load (HP) at 80 km/hr. Generally, Clayton mechanical dynamometer tests will over predict energy consumption if the majority of the test run takes place at low speeds. The J227a Schedule C cycle has an average speed of approximately 25 km/hr.

The electrical chassis dynamometer used by Davis Engineering Limited provides control of each of the coefficients in the road load equation:

$$A + BV + CV^2 = F$$

An accurate representation of road load, particularly at low speeds, is therefore possible.

c) A third source may be the SAE cycle itself. A straight line uniform acceleration is not practical and usually involves much higher initial acceleration in order to reach the constant speed point. With different drivers, this may introduce different energy consumption results and introduce differences in distance covered per cycle.

6.3 Vehicle Range

The results obtained were based on the Hagen lead acid battery pack.

6.3.a Constant Velocity Range Tests

DAVIS

The constant speed range tests were performed at the Transport Canada Motor Vehicle Test Centre in Blainville, Quebec, on the low speed track. The

test track is a 6.9 km oval with flat curved sections. The track surface is asphalt.

The testing was performed per the Tennessee Valley Authority procedure. Each test sequence included the following:

- Charge batteries to full capacity,
- Tow vehicle to test track,
- Switch on data acquisition system to record data,
- Accelerate vehicle to 56 km/hr in normal manner,
- Cruise at 56 km/hr in third gear until maximum vehicle speed is 95% of test speed, (53.2 km/hr),
- Terminate recording of data, and,
- Move vehicle back to charging area.

The test was performed three times.

Energy consumption and range during the tests was 643, 555, and 560 kJ/km and 60.9, 74.1 and 74.6 km respectively (Table 6.3a).

6.1.2 MTC

The MTC constant speed range test was conducted on the dynamometer. The dynamometer settings were the same as those specified for the SAE J227a Schedule C cycle tests. The criteria for acceleration, cruise and cut-off speed were the same as that specified in the TVA procedure, (see Table 6.2g). Results are presented in Table 6.3b, c. Energy consumption and range averaged 515 kJ/km and 67.6 km respectively. Table 6.3d shows the data for energy consumption and range when the vehicle was soaked at -15°C. The results, as expected, did not show significant variation because of the battery thermal management system.

Comparison

The results of the four (4) constant speed range tests are similar. The significant difference between the two of the three tests conducted by DAVIS may be attributed to temperature differences (-4 vs +16 and +8°C). The impact of temperature may be due to the fact that the vehicle was unplugged and towed for 30 minutes prior to testing.

The difference between the MTC run and the DAVIS runs conducted at nominally similar temperatures are marginal (515 vs 555, 560 kJ/km) and fall well within experimental testing error parameters. Besides temperature, the effect of total payload, driving conditions and road conditions could also have had an affect on the total range.

6.3.c Range - SAE J227a - Schedule C

MTC

The range as determined during the MTC dynamometer tests was 35.1 km. The test was deemed to be completed when the vehicle could not reach 48 km/hr in 20 seconds. In contrast Davis Engineering did not measure range on the dynamometer due to the limitation of the storage capacity in their Data Acquisition System which limits the dynamometer test to 35 cycles.

During this, the energy consumption per kilometer measured by Davis Engineering was 722 kJ/km vs 975 kJ/km for MTC.

6.4 VEHICLE ACCELERATION/MAXIMUM SPEED/BRAKING DISTANCE

The fully charged test vehicle is accelerated from rest to its maximum speed. Since the vehicle has manual transmission, the driver shifts gears at the recommended speeds. The elapsed time from zero to maximum speed is

recorded. From maximum speed, the vehicle is stopped as quickly as possible by applying the foot brakes. The distance travelled by the vehicle in stopping is measured with a fifth wheel. This procedure is repeated twice, alternating directions for each run. For these two runs, the vehicle is only accelerated to 80 km, allowed to coast from this speed to 48 km/hr and is then braked to a stop while the distance travelled is mesured as before (see Table 6.4a).

The vehicle is recharged and discharged until 80% of capacity has been removed and the acceleration and maximum speed tests is repeated.

Test results showed that average acceleration from 0 to 50 km/hr required 16 seconds at 100% charge. However, at 80% discharge the acceleration time from 0 to 50 km/hr was 58 seconds.

Maximum distance required to fully stop the vehicle from a speed of 50 km/hr was 25 meters on dry pavement.

Maximum speed attained was 92 km/hr.

Gradeability at 50 km/hr is approximately 6.1% (Table 6.4b) i.e. at 6.1% gradeability, the vehicle can maintain 50 km/hr speed.

6.5 Efficiency

Efficiency has been calculated, based on vehicle road load power vs battery power. Separate efficiency relationships have been determined for energy consumption (vehicle road load power/battery power) and energy regeneration (battery power/vehicle road load power).

6.5.a Vehicle Operational Efficiency

On-Road Results

During the DAVIS testing one set of typical operation test segments was driven with torque transducers on the drive wheels. Data has been analyzed to determine on-road consumptive and regenerative efficiency.

The results of the "OUT" and "RETURN" runs on each test section (vehicle power vs battery power) have been averaged on a common plot (Figures 6.5a-d). The results of the four test segments have been averaged in order to define the on-road efficiency.

Average Consumptive Efficiency

During Energy Consumption:

$P_r = 0.673\ P_b + 0.476$

where:

P_r = road load power (kW)

P_b = battery power (kW)

Average Regenerative Efficiency

During Energy Regeneration:

$P_b = 0.223\ P_r + 0.934$

Dynamometer Results

Vehicle road load power vs battery power was plotted for eight cycles for each of three test runs conducted on the dynamometer. Figure 6.5e provides a typical plot based on the Davis Engineering results.

Average Consumptive Efficiency

During energy consumption:

$P_r = 0.745\ P_b - 0.260$

When the vehicle power is zero, the electrical parasitic loss is 0.35 kW.

Average Regenerative Efficiency

During energy regeneration:

$P_b = 0.237\ P_r + 0.923$

Comparison - Dynamometer vs On-Road

A comparison of the operational efficiency results (Table 6.5) indicates that the consumptive efficiency on the dynamometer was nominally 7% higher than it was on the road (74.5% vs 67.3%). The differences have been attributed to:

a) The additional parasitic losses required during on-road operation. These losses would include headlights (low beam) and signal lamps.

b) Schedule differences in the driving cycle. The number and level of the acceleration segments varies between dynamometer and on-road tests. High acceleration and the corresponding low efficiency is more likely to occur during on-road testing.

6.5.b Charging Efficiency

The battery charging efficiency can be quoted when charging time is defined. Table 6.5a provides efficiency figures under defined charging conditions for two consecutive days. The charging times involved were 15 h, 20 min and 17 h respectively. The temperatures on both days were 21°C. The

estimated temperature in the storage building for both days was 25°C.

The mean charger efficiency, i.e., from 240 V ac to 108 V dc was 77.8%.

6.5c Battery Efficiency

The mean battery charge efficiency, calculated from the WH output to WH input, was 76.5% (Table 6.5b).

6.6 Comparison (Electrical vs Internal Combustion)

Table 6.6 provides the results of dynamometer tests conducted at Davis Engineering on an internal combustion engine powered vehicle having approximately the same GVW rating as the electric van. Based on an assumed net heating value of 32 MJ/litre the energy consumption for the gasoline vehicle varied from 2432 kJ/km (HWFCT) to 3680 kJ/km (steady state 125 km/hr). This is considerably more than the electric van energy consumption during the SAE J227a C tests and constant speed tests at 80 km/hr (720 kJ km and 800 kJ/km, respectively).

The average tractive energy consumption during the SAE J227a C cycle is 560 kJ/km. Based on average energy consumption of 720 kJ/km the efficiency is approximately 75%. Since the nominal charger efficiency from 240 V ac to 108 V dc was calculated to be 77.8%, the overall efficiency, based on the 240 V ac grid is approximately 58%. This however does not include the power station and distribution losses.

For the Urban Dynamometer Driving Schedule (UDDS) cycle the fuel consumption was 10.6 l/100 km which corresponds to 3392 kJ/km. Assuming that the tractive energy consumption is similar to that required during the SAE J227a C cycle the efficiency is approximately 17%.

6.7 Observations

As a result of the test programs, which were conducted by Davis Engineering Limited and the Ontario Ministry of Transportation and Communications, the following conclusions are submitted:

a) The range in the results of the Transport Canada method of estimating vehicle tractive energy, varied from 13.9% (4 Out) to 104.3% (2 Out) during energy consumption. The most accurate results were 104.3% (2 Out) and 94.0%
(2 Return).

During energy regeneration the results varied from 97.9% (3 Out) to 127.0% (3 Return). The best accuracy achieved was 97.7% (3 Out) and 108.2% (2 Out). Accuracy greater than 100% is expected during regeneration due to the frictional energy, which is dissipated by the rear brakes and not measured.

These results are based on a regressive analysis of estimated vs measured road load power.

b) There was only one MTC road test with which to compare to the DAVIS results. Although it fell within the points established by the DAVIS tests there is not enough data to determine whether the MTC results are similar to the DAVIS results. There was a significant amount of scatter in the on-road test results.

c) Significant differences between the MTC and DAVIS energy consumption values during the dynamometer tests have been attributed to different dynamometer set ups and types of dynamometer. The dynamometer, on which the MTC tests were conducted, (Clayton - mechanical) is not as accurate

at lower speeds as the DAVIS unit (Horiba - electric). The inertia weight settings were also different. Additionally, there are difficulties in driving to comply exactly to the 'C' cycle requirements.

d) Range, as determined during constant velocity range tests per TVA procedures, varied from 60.9 km to 80.4 km. DAVIS and MTC tests, conducted at nominally similar temperatures, resulted in similar ranges (74 km and 80 km).

e) Range determined by MTC during SAE J227a Schedule C testing was 35 km.

f) Comparisons indicate that the electric powered van, on the J227a Schedule C cycle, is more efficient than the gasoline powered van, on the UDDS cycle. The nominal values are 58% and 17% respectively.

(g) (i) Based on the results of the DAVIS tests:

- Nominal consumptive efficiency during on-road tests was 67.3%
- Nominal regenerative efficiency during on-road tests was 22.3%
- Nominal consumptive efficiency during dynamometer tests was 74.5%
- Nominal regenerative efficiency during dynamometer tests was 23.7%

(ii) Based on the results of the MTC tests the mean charger efficiency was 77.8%. The mean battery charge efficiency was 76.5%.

7. CURRENT BATTERY TECHNOLOGY

As an electric vehicle power source, an appropriate battery must fulfill many requirements. Among the most important being:

- high energy density for long range
- high power density for good acceleration and hill climbing performance
- long life and low maintenance for low vehicle operating costs
- simple to install and operate
- low materials and manufacturing costs
- low maintenance
- low self-discharge and good shelf life
- rapid and efficient rechargeability
- ability to operate under wide range of ambient conditions
- safety in operation and crash worthiness

In view of this wide range of criteria, it is not surprising that the search for a better battery remains a major priority in developing traffic compatible road electric vehicles.

There are many types of battery systems being developed but no single battery system has shown the ability to meet all of the above criteria. The U.S. Department of Energy has projected the battery requirements for a typical electric vehicle to be:

Energy Capacity	20 to 50 kWh
Voltage	100 to 250 v
Efficiency (D.C. to D.C.)	70% minimum
Life	800 cycles - 3 years minimum
Specific Energy	70 Wh/kg (3h rate) minimum
Volumetric Energy Density	140 Wh/litre
Specific Power	130 W/kg (15 sec. peak @ 50% discharge) minimum
Cost	$70/kWh (1982 $U.S.)
	$98/kWh (1982 $Cdn.)

The U.S. Electric Vehicle Development Corporation (EVDC) indicates a specific energy of at least 80 to 90 Wh/kg will be necessary to meet the demands of the passenger car market.

Reliability for all types of battery systems involves minimizing the impact of individual cell failures on battery performance and life. For E.V. applications the battery voltage and capacity indicate the need for many cells in series and a smaller number in parallel. This condition strongly affects the cell interconnection system and cell design. The average loss of cell life is currently 10% after 500 cycles. Assuming 250 km per charge-recharge cycle, this translates into 125,000 km with 10% cell loss.

Battery safety and durability must be also of primary concern during design to include the detrimental factors such as road shock, vibration, vehicle impact and electrical stresses during operation. High temperature batteries, by their nature, require factory sealed casings. The battery enclosure must withstand violent impact as sodium reacts violently with water and ignites the hydrogen released.

The following brief synopsis is indicative of the current battery systems being developed for electric vehicles. These have been divided into two groups: near term availability - those batteries that should be available for E.V. use before 1990, and long term availability - those batteries that will not be available until after 1990.

7.1 Near Term Battery Systems

a) Lead-Acid

The history of lead-acid batteries extends beyond the turn of this century. This system has enjoyed very extensive research and field trials over the years thereby accumulating a wealth of knowledge from an application point of view. There is extensive field experience with lead-acid batteries. Leading developers of lead-acid battery technology include Lucas Chloride in U.K., Varta and Hagen in Germany, Johnson Controls, Globe, Exxon, Gould and Westinghouse in U.S.A., Yuasa, Shin-Kobe and Japan Storage in Japan.

There has been a difference in the approach to lead-acid battery development between the Europeans and the American-Japanese effort. The Europeans have stressed reliability and long life while the American-Japanese have stressed high power and energy densities which has resulted in shorter life.

Future development in lead-acid battery will be directed at increasing energy density, cycle life and reducing maintenance.

Increasing energy density will be achieved by reducing the weight and volume of the battery. Life cycle improvement will be achieved by finding better plate separator materials, achieving good thermal management of battery packs and elimination of electrolyte stratification.

The major maintenance work for lead-acid cells is the addition of water to replace that which is lost mainly due to electrolysis, and to a lesser extent by self-discharge reactions and evaporation. To lessen the amount of time needed to add water to each cell, single point watering systems are now being used which reduce the time required for watering to seconds. This disadvantage can be significantly reduced by optimizing charging methods, or avoided by designing "maintenance free" batteries using grids consisting of antimony-free lead calcium mesh.

Energy and power densities of lead-acid traction batteries are approximately 30 Wh/kg and 100 W/kg respectively, with cycle life range between 600-800 cycles and DC to DC energy efficiency approaching 75%. Energy and power densities are adversely affected by cold temperatures necessitating thermal management systems.

A safety concern with lead-acid batteries is that hydrogen gas is produced during charging. An explosive hydrogen atmosphere could be created as well as the possibility of explosion due to the buildup of high internal pressure. Gas collection and venting systems are available and work is being done on a sealed gel cell which does not evolve hydrogen.

b) Nickel-Iron Batteries

Nickel-iron batteries have been available for approximately 80 years and have been employed for traction applications (e.g. mine locomotives), particularly in European countries.

Ni/Fe batteries have a tradition of very long cycle life (approximately 1500-2000 cycles). Power density is reported to be 120 W/kg and the energy density is 28 Wh/kg. The goal is to increase the energy density to 55-70 Wh/kg. Charge retention properties are similar or worse than lead-acid batteries. The operating temperature is -18°C to 50°C (0°F to 122°F). The capacity is drastically reduced at low temperature.

The high cost of nickel is a major disadvantage of the Ni/Fe batteries. There is a chance that the Ni/Fe batteries will achieve commercial use but costs are so high that they may keep the battery out of the market.

Some of the specific design features in current electric vehicle nickel-iron batteries are single point watering systems similar to the lead-acid. To increase safety and prevent possible explosions due to hydrogen gas accumulation, Eagle Pitcher (U.S.A.) have introduced a hydrogen gas dilution system and a flame arrestor.

Major organizations working with nickel-iron batteries for electric vehicle application include Westinghouse, Eagle-Pitcher Industries (U.S.A.), and SAFT (France), Varta (Germany) and Matsushita Electrical Industries Co. (Japan).

c) Metal-Air Batteries

Most of the development effort for electric vehicle applications has been in zinc, iron and aluminum air cells. Most metal-air systems use alkaline or near neutral saline electrolytes.

Electrical or mechanical recharging can be employed optionally for metal/air batteries with Zn, Fe, or Pb electrodes. Among these, Zn is the most electro-positive element that can still be plated out from aqueous solutions and thus be electrically recharged. Zn has been applied in the form of conventional plates or as a powder slurry. In the latter case, electrical recharging can be performed either in the battery itself (internally) or in a special recharging or electrolysis cell (externally).

Electrical recharging is not an option for the reactive metals, Al, Li and Mg. These highly electro-positive elements evolve hydrogen at high rates in aqueous solutions at the potentials necessary for recharging; they can only be recharged mechanically.

The aluminum-air battery system is recharged by replacing the aluminum anode plates, refilling the water and transferring the reaction product to a separate container where the by-product is precipitated. The hydrated alumina is separated and washed automatically. The alumina can then be removed and sent to the aluminum industry for refining in existing plants.

Some of the anticipated advantages of metal-air battery systems include fast refuelling, high energy density, and environmentally benign by-products for which the technology is available to recycle back into useable material. The problem areas include low power density, high cost of energy, and parasitic anode corrosion reactions. Additionally, the cells operate at high temperatures and require conditioned air supply to remove carbon dioxide and water.

The Fe/air battery suffers from high self-discharge of the iron electrode (about 2% of the capacity per day at 25°C), poor charge efficiency (about 40% or less), low utilization of active materials, limited power capability (30-40 W/kg maximum), a low cell voltage, and thermal problems. Another problem lies with cost of designing an efficient, simple auxiliary system for the battery. The auxiliary system is required for circulating electrolyte and air, cooling, water makeup and carbon dioxide removal from the air.

Apart from air electrode problems, the main difficulty with Zn/air systems lies in the instability of the zinc electrode. The zinc oxide formed during discharge dissolves in the electrolyte to give zincate ions, and redeposition of zinc during charging leads to the problems of electrode shape change and dendritic growth. Attempts to produce even zinc deposits by the high speed circulation of electrolyte have not resulted in any significant

improvement in cell lifetime or performance. The use of fluidized electrodes has also proved unsuccessful. A more promising concept is that of using a circulating system of zinc powder suspended in the electrolyte. The cost of handling such a system becomes quite expensive.

The Al/air battery provides a very high energy density and therefore could provide an E.V. with a range performance approaching that of present-day ICE vehicle. The major limitation is a low energy efficiency. This is less than 15% of the original energy used to produce the aluminum. The system also has excessive self-discharge due to reaction of aluminum in the alkaline electrolyte with concomitant generation of hydrogen.

The Fe/air battery is electrically rechargeable and is based on the long lived, rugged and inexpensive iron electrode. Its theoretical specific energy is 4-6 times that of lead-acid batteries. Its limitations of short life and relatively low power density and efficiency, are mainly related to the bifunctional air electrode.

The zinc-air battery is electrically or mechanically rechargeable. Zinc is inexpensive and its electro-positive character results in attractive cell voltage and specific energy. The theoretical specific energy is 5.3 times that of lead-acid batteries. When electrically recharged, the zinc electrode is subject to the cycle life limitations of all alkaline zinc batteries.

The aluminum-air battery is strictly mechanically rechargeable. It has an exceptionally high theoretical specific energy, which is nearly 17 times that of the lead-acid battery.

The air electrode remains the most limiting feature of all metal-air batteries. Besides being expensive, it limits the life, energy efficiency and power density. The development of an economical non noble catalyst is a prerequisite for metal-air batteries to become viable for electric vehicle application. This is expected to materialize within 10 years.

d) Sodium Sulphur Batteries

The sodium sulphur batteries have been under development for electric vehicle applications since the mid-1970's. The sodium sulphur cell comprises of a liquid sodium anode and a liquid sulphur cathode separated by a solid sodium-ion conducting ceramic, Beta-alumina. Both sodium and sulphur are cheap and plentiful and are attractive for use in large volume markets.

The operating temperature range, 300-350°C, is limited by the precipitation of sodium polysulphides at the lower level and by the vapour pressure of sulphur at the upper level. Thermal enclosure is required to maintain the overall battery efficiency above 75% during application. In order to maintain the designed operating temperature, the battery core must contain both heating elements, to maintain the battery at operating temperatures during non-operation, and a cooling system for continuous operation during high power requirements.

The most critical component of the cell is the Beta-alumina electrolyte which forms the focal point of much research and development effort. Major problems arise in the assembly of cells into batteries, and in the variability in performance of the Beta-alumina electrolyte.

Most cells are tubular consisting of a ceramic electrolyte which is sealed into a cylindrical metallic can. Hermetic seals are required between the ceramic tube and the insulating separator, and between the separator and the metal can. Seal leakage and degradation limit the operational lifetime of NaS cells, as well as corrosion of the container material by the polysulphide melt.

The pioneer work on NaS battery was done by Ford Motor Co. Further research is being done in England (Lucas Chloride, British Rail), France (Compagnie Generale d'Electricite), Japan (Yuasa Battery Co.) and others.

However, the most advances in developing an E.V. NaS battery has been accomplished by Brown Boverie & Cie. of Germany and their joint venture company with Magna International of Canada called Powerplex Technologies Inc. (see next chapter).

7.2 Long Term Battery Systems

a) Lithium Aluminum - Iron Sulphide Battery

The lithium aluminum-iron sulphide battery system is similar to the sodium sulphur system. The critical design parameters are as follows:

- minimum weight and high packing density
- efficient thermal management
- high reliability, and,
- durability and safety in service

These concerns must be addressed during the development process of the total system. This technology is in its preliminary stages and a prototype production battery will not be available within the next five years. Gould Manufacturing Ltd. have developed two 3 kWh modules for Argonne National Laboratories (ANL) using magnesium oxide (MgO) separators. On the other hand Electrofuel Manufacturing Co. of Canada have developed modules using boron nitride (BN) felt separators which have shown better performance than the MgO separators. Argonne originally wanted to develop a high performance battery using BN felt separators. However, because of the high cost of the BN felt, Argonne redirected the development towards the utilization of a lower

performance powder MgO separator. Electrofuel of Canada have been able to reduce the price of the BN felt separators to a reasonable value by development work of their own and that of the Ontario Research Foundation. Thus their first prototype battery will be a high performance battery using BN felt separators.

From an engineering standpoint, there may be a number of advantages over the sodium-sulphur system such as:

- cycle life is projected to be greater than or equal to 1200 cycles
- slightly higher volumetric energy density
- freeze-thaw cycles are not harmful to battery life
- fast charge rate can be as high as 30 minutes to 70% capacity - this is limited by the charger which is in turn limited by the weight of the transformer
- overcharge protection is a feature of the cell electrochemistry
- more durable against shock and vibration
- easier to manufacture

The Li Al/Fe S battery is relatively safe compared to other batteries. The amount of liquid chloride electrolyte is small in each cell so spillage would be minimal if the cells are opened. The cells have a low heat capacity so the electrolyte would solidify quickly . Lithium is alloyed with aluminum, eliminating the explosive dangers caused by pure lithium. The only problem may be associated with the high operating temperature of 450°C.

b) Lithium-Molybdenum Disulphide

A lithium-molybdenum disulphide system has been under development by Moli Energy Ltd. (Canada). Their projection for a prototype E.V. battery is estimated to be 1988.

This battery system will consist of an arrangement of cells to achieve the required voltage and capacity. Currently cell energy density is reported at 105 Wh/kg. Current power density is 120 W/kg and the development goal has been targeted for 250 W/kg.

The potential advantages for this type of system are:

- excellent energy and power densities
- the cells are designed to operate at ambient temperatures
- energy efficient 90%

The inherent disadvantages of the Moli system may be for example:

- capacity at low winter temperatures is very much reduced - the minimum operating temperature is -15°C (although this can be overcome by thermal management system)
- the lithium in the battery may create a serious safety hazard

If the energy and power densities were increased to the desired higher values, the vehicle range will more than double the range of an equivalent lead-acid battery, and the acceleration capability will also be improved.

The optimum operating temperature of the Li-MoS_2 system is -15°C to +60°C. Since this battery system need not be maintained at elevated tempreatures, considerable energy savings may be achieved. The energy efficiency (ratio of energy delivered by the charging system to energy extracted from the battery) is anticipated to be greater than .9. This efficiency when compared to a typical lead-acid system with an efficiency of .75 is also an advantage. The problems with this type of system are generally

associated with low winter ambient temperatures, where capacity may be very much reduced. In the event of a serious accident, the lithium in the cells must be contained to prevent a serious safety hazard. The lithium in the cells in contact with water (rain) converts explosively into lithium hydroxide and hydrogen. The hydrogen can ignite and cause severe problems.

c) Nickel-Zinc Batteries

The nickel-zinc system has been known since the start of this century. The energy density of a well designed system is about 70 Wh/kg at the 3 hr discharge rate which is adequate for electric vehicle applications. The most attractive feature of nickel-zinc batteries is the power density. The thirty second sustained specific power at 50% depth of discharge is 131 W/kg. This is reflected in the excellent acceleration capabilities of vehicles powered by nickel-zinc cells.

A fully charged nickel-zinc cell at 25°C self discharge at a rate of 0.8% per day during the first 60 days. Thereafter, the self discharge tapers off. This effect is reduced at lower temperatures.

Cycle life has been a chronic problem with nickel-zinc batteries. The failure modes have been related to oxidation of the separators, zinc electrode shape change and penetration of the zinc through the separator.

These batteries tend to be expensive due to the high cost of nickel.

No manufacturer is known to be developing this battery system or is prepared to indicate their intentions.

d) Nickel-Cadmium Batteries

Nickel-cadmium batteries have limited energy densities that provide a somewhat limited range for electric vehicles. Their high power levels is very attractive for use in hybrids. A major economic drawback is the high price of

nickel and cadmium. No one has reported that they have or are planning to develop nickel-cadmium batteries for use in electric vehicles.

e) Zinc-Halogen Batteries

Although zinc chlorine and zinc bromine batteries have been known for over one hundred years, development activity did not really commence until the 1970's. Both systems have been demonstrated scientifically and present efforts by Exxon Research and Engineering (zinc bromine) and Energy Development Associates (zinc chlorine) are directed towards commercial production such as load leveling applications. A zinc chlorine production prototype has been constructed and it has been demonstrated in vehicles by Energy Development Associates in the U.S.

Manufacturing costs have not been published to date, however, zinc bromine may become cheaper due to the fact that bromine is easier to store than chlorine hydrate.

Based on single cell performance, zinc bromine characteristics are: energy density 60 Wh/kg and power density 100 Wh/kg. Zinc chlorine characteristics are: energy density 100 W/kg and power density 150 W/kg. In spite of the complexity of the electrolyte circulation system needed to operate both ZnCl and ZnBr it does permit a simplistic heat removal system using a radiator. The ambient temperature operation is a distinct advantage. Materials of construction are inexpensive and readily available.

It appears that the life cycle of zinc bromine systems may be 1000 cycles and zinc chlorine last in excess of 2500 cycles.

Circulating zinc-halogen batteries in terms of weight, life-cycle, and cost may offer the favourable consideration for use in electric vehicles.

8. COMPARISON OF HAGEN LEAD ACID AND BBC SODIUM SULPHUR (B06) BATTERY SYSTEMS

BBC has been credited with the development of the sodium sulphur battery to the stage where prototype batteries were installed in vehicles and tested. Powerplex Technologies Inc., a joint venture company of BBC and Magna International of Markham, Ontario, retrofitted a BBC sodium sulphur battery system into one of the three T115 electric vehicles (EV03). The vehicle was tested by MTC and results compared to the T115 electric vehicle equipped with lead acid battery system (EV02).

The two B06 56 volt NaS battery systems were connected in series and placed on the rear floor of the van. The technical details are as follows:

Battery configuration	Two experimental 56 V NaS batteries with 224 cells each, series connected. Two complete thermal management systems.
Rated voltage	112 V
Rated capacity	250 Ah
Battery weight	394 kg (excluding mounting hardware)
Battery volume	358 litre (including thermal management system

Features of the B06 - NaS battery system include:

- maintenance free operation
- no gas (hydrogen) production
- electronic thermal control system
- super insulated battery enclosure
- forced air cooling

In comparison, the Hagen lead acid battery contains 18 - 6 volt modules connected in series to provide a voltage of 108 V and a battery capacity of 143 Ah. The overall weight of the battery including thermal management and hardware is 550 kg.

MTC performed road and dynamometer tests. All tests were conducted with the vehicle loaded to the maximum rated GVW to compensate for weight variation between the two battery systems (lead acid vs NaS).

Operating Comparison

This was a unique opportunity to test two different battery technologies on identical vehicles with the same voltage and current limits. The following describe and analyze the results obtained. The results are shown in Table 8.1.

1. Power Delivery During Discharge

The performance of the lead acid system during discharge showed significant increase in internal resistance whereas the sodium sulphur system maintained a constant resistance through discharge. Furthermore, the voltage of the system was very stable and at full discharge was approximately 15% less than the full charge voltage.

The effect of the NaS system on acceleration of the vehicles from 0 to 48 km/hr is shown in Figure 8.1. Although at full charge both systems performed identically (16 sec), the sodium sulphur system showed a slight increase in performance (17 sec) at 80% depth of discharge, whereas the lead acid system showed a significant drop in performance (58 sec) at 80% depth of discharge.

This characteristic of the sodium sulphur system showed an excellent driveability throughout vehicle range as well as increased vehicle range.

Vehicle Range Performance

The increase in vehicle range achieved is shown in Figure 8.2. The figure illustrates the range vs depth of discharge for both the lead acid and sodium sulphur battery systems during the SAE J227a C cycle and the constant 56 km/hr test. The test results showed a significant increase in range of the NaS system over the lead acid as expected. The SAE J227a C cycle test showed a range of 85 km for the NaS system vs 35 km for the lead acid, while the constant speed test showed the NaS system to have a 209 km range vs 81 km for the lead acid system.

In both cases the sodium sulphur battery supplied sufficient power to meet the test criteria until full discharge was achieved whereas the lead acid did not. During the constant speed test the lead acid battery fell below the 53 km/hr cut off speed at 79.5% depth of discharge. Similarly, during the J227a C cycle test, the lead acid battery performance fell below the test criteria at 68.4% depth of discharge.

It is apparent from these tests that given batteries with the same energy density, a sodium sulphur battery would still provide a greater vehicle range than a lead acid system in any practical driving test.

The limited tests performed on the EV03 vehicle indicate that the sodium sulphur battery technology can provide excellent range and performance in smaller vehicles which are not capable of carrying the weight of large conventional battery systems.

A new and more advanced B11 sodium sulphur battery is now ready to be tested in these types of vehicles. Powerplex Technologies Inc. are working with BBC to produce a number of these batteries which will be installed in the Chrysler T115 vehicle during 1987.

9. CONCLUSIONS

1. The Chrysler T115 electric vehicle conversion project, initiated in Ontario, involving the Ontario Centre for Automotive Parts Technology as Program Manager has met all of its objectives.

2. The T115 electric vehicle behaves in a similar fashion to its gasoline counterpart, but range is limited by battery kilowatt-hour capacity. Since the controller and motor are limited to 300 A, the vehicle acceleration and speed are determined by the battery voltage (250 volts maximum).

3. Vehicle electrics and drive system are reliable. It is possible that these can be used with other (advanced) battery systems.

4. Net energy consumption for a constant speed of 80 km/hr was 800 kJ/km. This compares favourably with 2656 kJ/km for a comparable gasoline powered vehicle at a steady state speed of 100 km/hr.

5. The vehicle, when equipped with a temperature controlled battery system, is not adversely affected by wide ranges in ambient temperature (-5°C to 25°C).

6. Suitable traction batteries are not available at this time for commercial application and this remains as the key technological impediment to the use of on-the-road electric vehicles in commercial service in Canada.

10. OBSERVATIONS

1. The program initiated by Ontario in cooperation with Energy Mines and Resources Canada appears to have been timely in terms of market conditions and technology development.

2. The implementation of this program has been responsible for the creation of a new joint venture company in Ontario, Powerplex Technologies Inc., bringing together world leaders in the electrical equipment industry from Europe (Brown, Boveri & Cie.) and the north american automotive industry (Magna International).

3. Ontario is now recognized as a leading centre of electric vehicle and advanced battery development. This has resulted in the choice of Canada as the site of the next major international conference in Electric Propulsion in 1988.

4. Considering the limitations in range of the Chrysler T115 vehicle due to the lead acid battery, there appears to be limited commercial application for such a vehicle. The introduction of the more advanced sodium sulphur battery should expand the commercial viability of such an electric vehicle. The U.S. Department of Energy is moving towards commercial utilization of such a vehicle.

11. RECOMMENDATIONS

1. The Chrysler T115 vehicles, with suitable modifications are capable of, and should be used to evaluate new battery types and electric components. These should also be used for electric vehicle demonstration purposes.

2. Powerplex Technologies Inc. are nearing the time when an on-road demonstration of their advanced sodium sulphur battery system will be required. The Chrysler T115 vehicles should be used to test these batteries which could be considered as an Ontario contribution towards the development of such a demonstration project.

3. Certain mechanical components of the Chrysler T115 mini van should be modified to improve the performance of the electric version of this vehicle. Components such as transmission, rear axle, and power steering can be improved for use with electric drive systems.

4. Programs to develop strategic components for electric vehicles should continue to receive government support.

5. In view of the rapid technological developments in this field, it is recommended that the electric vehicle steering committee meet at 6 month intervals over the next 2 years to review the situation and to consider what government measures may be appropriate.

APPENDIX I

MTC

INSPECTION AND TESTING PROGRAM

for

Chrysler T115 Electric Van

1. Preliminary Vehicle Inspection

2. Vehicle Operating and Handling

3. Power Requirements for Constant Speed

4. Energy Consumption for Maximum Acceleration and Maximum Speed

5. Vehicle Acceleration and Maximum Speed

6. Test on Dynamometer

7. Radio Frequency Interference

8. Reliability

9. Instrumentation

TEST PROGRAM

1.0 Vehicle Inspection

This part of the program is directed to ensure that the vehicle is fit to drive and safe. Vehicle operation and handling tests will be carried out if the vehicle appears to be road worthy.

1.1 Vehicle Inspection Procedure

A visual inspection of the vehicle will be carried out when it is delivered to MTC. Any physical damage or missing parts will be recorded on the Vehicle Inspection Sheet (VIS), and the supplier, namely Powerplex, will be notified for corrective action.

The nameplate data and serial numbers of the vehicle and major components are to be recorded on the VIS sheets. Discrepancies from the vehicle specification to be noted and reported to the project manager. The state of vehicle preparation, namely fluid levels, cable connections, tire pressures, battery charge conditions, etc. be examined carefully and be corrected as necessary.

The vehicle curb weight and axle loadings will be determined. The results are then noted and compared with the specification.

2.0 Vehicle Operation and Handling

It is a subjective evaluation of the vehicle operation and handling. All vehicle controls, namely acceleration, braking, battery charging, and all auxiliary functions be verified for their correct and safe operation. Deviations will be noted and corrected if possible. Deviations will be tolerated ONLY IF safe vehicle operation is not compromised.

The handling test is to ensure that the added battery weight at the rear does not affect the steering and braking characteristics.

2.1 Test Procedure

Operators will become familiar with all controlling features of the vehicle:

- : verify their correct and safe operation;
- : note and correct any discrepancies from specification;
- : the handling test will be performed only if all controlling functions of the vehicle have proved to be functioning or not interfering with safe operation.

A series of braking tests will be performed to examine the dynamic behaviour of the vehicle under both dry and wet pavement conditions. Driver's opinion of the vehicle handling in normal driving and braking will be surveyed.

3.0 Power Requirements for Constant Speeds

The purpose of the test is to determine the power input into the motor armature for a given speed on a level road. The data will be used to set up the dynamometer resistance characteristics.

3.1 Test Procedure

Measurements are to be taken at constant speed state with the gear box set at the appropriate position. Tests will be carried out at other gear positions to see if this has any significant effect on results. The constant speeds to be tested are: 20, 40, 60, 80 km/hr and the maximum cruising speed.

The maximum test speed will also be performed under full charge and 80% discharge battery conditions.

4.0 Energy Consumption for Maximum Acceleration to Maximum Speed

The purpose of the test is to obtain the energy consumption figure for the vehicle to accelerate to its maximum speed in the shortest duration on a straight level road.

4.1 Test Procedure

The test will be performed under full charge and 80% discharged battery conditions. The distance travelled and the time elapsed for the vehicle to reach 50 km/hr will be recorded as well. Gear ratio, other than the most efficient setting, will be tried out to check if the results are different.

5.0 Vehicle Acceleration and Maximum Speed

Vehicle maximum velocity and acceleration versus time curves will be obtained from the energy consumption test (4.4) for maximum acceleration to maximum speed test.

6.0 Test on Dynamometer

The dynamometer is used to test the vehicle gradeability and to obtain the d.c. energy consumption on a driving cycle such as SAE J227a C and D.

6.1 Energy Consumption Test

The purpose of the SAE J227a C and D cycle tests are to determine the distance travelled and the energy consumed by the vehicle operated on a level surface in repeatable driving cycles involving periods of accelerating, cruising, coasting, braking, and idling. These energy consumption data may be used to compare the performance of different vehicles or of the same vehicle with different battery systems.

6.1.1 Test Procedure

Drive the fully-charged test vehicle on to the dynamometer. Initialise all equipment. Drive the vehicle following the speed versus time chart used (either C or D cycle). Repeat the cycle ten times. Record all pertinent readings.

6.2 Gradeability

The purpose of this test is in effect to measure the maximum tractive power output of the vehicle at various speeds.

6.2.1 Test Procedure

Drive the fully-charged test vehicle on to the dynamometer. Drive the vehicle at maximum acceleration rate to its maximum speed. Obtain the speed versus time curve. Derive the acceleration value at selected speed. The arc sine value of the acceleration to gravitational acceleration ratio is the gradeability of the vehicle at the selected speed.

7.0 Radio Frequency Interference (RFI)

The purpose of this test is to check if any RFI produced by the vehicle affect the receiving of an on-board AM radio and or a portable FM radio.

7.1 Test Procedure

Radio signal receiving will be tested under the following vehicle operation conditions:

: ignition switch off - charger off,
: ignition switch off - charger on,
: ignition switch on - constant speed at low motor rpm,
: ignition switch on - constant speed at medium motor rpm,
: ignition switch on - constant speed at high motor rpm,
: ignition switch on - constant speed at maximum motor rpm,
: ignition switch on - maximum acceleration from zero to maximum speed
: ignition switch on - regenerative braking from maximum speed to stop

If any interference is present which is not heard when the vehicle power is off, record the frequency. Repeat the frequency in a nearby I.C.E. vehicle and record the result.

8.0 Reliability

The purpose of this test is gathering data on the operating cost and the vehicle reliability when used in regular road conditions. Data to be gathered include but is not limited to the following:

: maintenance cost, both material and labour,
: heater fuel quantity and cost,
: battery maintenance cost, both material and labour,
: a.c. and d.c. energy consumption versus total km,
: failure report in detail.

9.0 Instrumentation

The use of expensive data acquisition instruments has been avoided by curtailing the sophistication of the tests. The present plan is to utilize integrating Watt hour and Ampere hour instruments wherever possible. Tape recording will be avoided if chart recording can provide all vital information. This tends to rule out the use of sophisticated data retrieval equipment after the test is finished.

The instrumentation to be used include:

: on-board 115 V a.c. power supply,
: on-board 240 V a.c. kilowatt-hour meter,
: d.c. Ampere-hour meter,
: d.c. Kilowatt-hour meter,
: d.c. voltage sensor,
: d.c. current sensor,
: vehicle speed sensor,
: portable tape data recording system,
: chart recorder.

APPENDIX II

TRANSPORT CANADA

MEASUREMENT OF THE ENERGY CONSUMPTION AND EFFICIENCY OF A T115 ELECTRIC VAN

(January 1985)

MEASUREMENT PROGRAM

1. General

The proposed measurement program consists of seven principal activities as follows:

(i) Vehicle instrumentation

(ii) Coastdown tests

(iii) Chassis dynamometer tests (initial)

(iv) Steady-state measurement on the road

(v) Typical on-road operation

(vi) Chassis dynamometer tests (final) (optional)

(vii) Vehicle deinstrumentation

It is assumed that OCAPT would be responsible for shipping the vehicle to Ottawa and returning it to Downsview or another specific location at the conclusion of the program. TC would bear all the direct costs of the measurement program as part of its ongoing research into motor vehicle energy consumption. It therefore reserves the right to depart in detail from the outline presented here if considerations of the cost/effectiveness of particular measurements of procedures warrant such a departure.

2. Vehicle Instrumentation

The vehicle will be equipped with a Davis Model 359-2 digital data acquisition system capable of sampling and recording the following variables at a frequency of 1 Hz.

(i) Time

(ii) Distance

(iii) Speed

(iv) Acceleration

(v) Ambient temperature; and

(vi) Total power consumption

In addition, the vehicle may be equipped to provide additional power measurements relating to the efficiency of drive train sub-systems, in particular, the regenerative braking system. Power consumption during battery recharging operations could be monitored by external means if desired.

3. Coastdown Tests

Weight and weight distribution of the vehicle will be determined with driver and instrumentation. The vehicle will then be subjected to a standard coastdown test procedure conducted and analysed as far as possible in accordance with the requirements of Reference (1).

The coastdown test procedure and analyses produce the following results for standard conditions of 20°C and normal barometric pressure:

(i) estimated values of the coefficients of v^0 and v^2 in the road load equation for the vehicle, to be used in analysing the energy consumption of the vehicle on the road; and

(ii) estimated values of the road load power at a designated speed (usually 50 miles/hr) and/or the coastdown time for a designated speed range (usually 55 to 45 miles/hr) to be used in dynamometer testing.

4. Chassis Dynamometer Tests (initial)

The vehicle will be subjected to two series of standard dynamometer tests representing typical urban and highway operations. The driving schedules to be followed remain to be specified but will most likely consist of the standard North American cycles modified as necessary to accommodate the limited acceleration and (possible) range performance of the subject vehicle.

Assuming the availability of the requisite transducers, torques at the drive wheels will be measured throughout the dynamometer tests so that the instantaneous tractive power demand on the vehicle can be determined as accurately as possible.

The dynamometer tests will provide measurements of the average energy consumption of the vehicle under standardized test conditions and an estimate of the overall efficiency of the vehicle in converting electrical energy to tractive work. If wheel torques can be measured, vehicle energy consumption can be mapped over the torque/speed range encountered in the specified driving schedules.

5. Steady State Measurements on the Road

A series of measurements of power consumption at various constant speeds will be made under conditions that reduce the effects of wind and gradient to a practical minimum. These tests provide vehicle mapping data to be compared with results obtained from the standard dynamometer tests.

6. Typical On-Road Operation

The vehicle will be operated over a test circuit on public roads that has previously been used extensively in measurements of the fuel consumption of passenger cars(2). The circuit, which is run consecutively in opposite directions, includes five measurement sections varying in length from 2.2 to 4.0 km over which the average speeds in normal driving range from under 20 to over 80 km/hr.

It is proposed initially to run the vehicle over the circuit five times in each direction, giving 5 x 5 x 2 = 50 simulated trips with an equivalent number of measurements of average energy consumption for analysis.

7. Chassis Dynamometer Tests (final)

The measurement procedures outlined under Section 4 above will be repeated at the conclusion of the on-road measurements to determine if any measurable shift in performance occurred during the steady-state and on-road testing. In view of the relatively small kilometrage that will be accumulated during those tests, the final dynamometer tests may be eliminated if MTC experience suggests that vehicle performance is reasonably stable.

8. Vehicle Deinstrumentation

The data acquisition system will be removed from the vehicle at the conclusion of the measurement program. Some or all of the associated sensors will also be removed unless it appears useful to leave them in place for any subsequent measurements by MTC or TC.

ANALYSIS AND REPORTING OF RESULTS

1. On-Road Energy Consumption

The analysis of data and the form of the results obtainable from coastdown, dynamometer and steady-state testing is more or less clear from the foregoing descriptions of the tests themselves. What may be got from the on-road measurements is perhaps less obvious and, in some respects at least, may not be fully evident until the analyses are complete. The two, not unrelated, approaches that will be used in analysing the on-road measurements are therefore outlined below.

The first approach is simply to fit an expression of the form:

$$\bar{c} = a_0 + \frac{a_1}{\bar{v}} + a_2\bar{v}^2 + E \qquad (1)$$

to the data, where $\bar{c}$ is the average energy consumption for a given trip, $\bar{v}$ is the corresponding average speed for the trip, E is the residual error and the values of the coefficients are chosen to minimize the mean square error in $\bar{c}$.

For a typical passenger car, such an expression is usually capable of explaining 70 to 90 percent of the variance in its energy consumption over a wide range of driving conditions. Some improvement in the coefficient of determination may be obtained by including an additional term in $\bar{v}$, although its physical interpretation is not clear. For measurements over a wide range of ambient temperatures, the inclusion of ambient temperature as a variable also reduces the unexplained variance and the value of its coefficient gives a first order estimate of the dependence of the vehicle's energy consumption on ambient temperature.

An expression of the form of Equation (1) is sufficient for many practical purposes. In the context of the present study, it could be used as a basis for monitoring the results of energy consumption measurements made with a bare minimum of instrumentation during simulated service experience by MTC. Its principal limitation is that, although the coefficients can be related theoretically to known characteristics of the vehicle and typical trips, in practice it is difficult to do so.

More fundamental analyses of the energy consumption of passenger cars (3) lead to expressions of the form:

$$\bar{c} = \frac{P_o}{\bar{v}} + \frac{W_T^+}{\eta_m} \qquad (2)$$

where $\bar{c}$ and $\bar{v}$ are as previously defined, P_o is the idle power level of the vehicle, η_m its marginal efficiency and W_T^+ the average value of the position tractive work per unit distance for the given trip. The vehicle parameters P_o and η_m may be determined independently by dynamometer testing or simple on-road mapping tests, while the value of W_T^+ is readily calculated for a given trip if the vehicle mass and coastdown coefficients are known.

In the case of the electric vehicle, the idle power level is likely to be small or zero and the energy consumption will be reduced by regeneration of power during deceleration. Assuming that P_o is effectively zero, the energy consumption of the electric vehicle may then be represented as:

$$\bar{c} = \frac{W_T^+}{\eta_m} + \eta_r W_T^- \qquad (3)$$

where W_T^- is the (negative) distance-averaged tractive work done by the vehicle on the drive train and brakes during deceleration of the vehicle. The parameter η_r is the efficiency of the regenerator system, here assumed to be constant.

Using the second (tractive energy) approach has a number of practical and theoretical advantages of which the most important in the present context is that it leads to basic measures of the energy conversion efficiency of the vehicle. Its practical disadvantage is that it requires a relatively sophisticated instrumentation system and more extensive preliminary measurements in order to determine the tractive energy characteristics of any given trip.

2. Reporting

The measurements and analyses outlined in the foregoing sections will be communicated to EMR in the form of two unpublished reports. The first, to be prepared by Davis Engineering Ltd., will document the vehicle, equipment and measurement procedures in detail and present the data in summary form. The second, to be prepared by the Vehicle Systems Division of TC, will describe the analytical procedures used and present the results of those analyses. Every effort will be made to provide these reports within 90 days of the conclusion of the measurements. A regression analysis of energy consumption on trip speed will be provided at the earliest possible date to indicate the expected performance of the vehicle in MTC operations.

Depending upon the value of the results obtained, approval to publish the results of the measurements and analysis may be sought.

REFERENCES

1. "EPA recommended practice for determination of vehicle road load", Attachment 1 to OMSAPC Advisory Circular No. 55B, U.S. Environmental Protection Agency, December 6, 1978.

2. "Further comparisons between passenger car fuel consumption in standard dynamometer tests and on the road". Final report on DSS Contract No. OSV82-00102. Davis Engineering Ltd., March 1984 (unpublished).

3. POST, K. et al Motor vehicle fuel economy - vehicle maps, power demand models and unsteady state engine maps. Final report to NERDDP by the University of Sydney. Charles Knolling Research Laboratory Technical Note ER-42, University of Sydney, February 1983.

APPENDIX IIa

ON ROAD TESTING - TYPICAL OPERATION

The vehicle was tested using the procedures and road testing sections that were used in a previous project conducted by Davis Engineering for Transport Canada entitled "Further Comparisons Between Passenger Car Fuel Consumption in Standard Dynamometers Test and Over the Road", Report No. 82-161.4, March 1984. The four road sections are displayed in Figure 2.2. Following is a description of each of the segments.

Section 1: Low speed urban test section which starts at the corner of Gladwin and Bourassa, goes west on Bourassa, south a St. Laurent, through the Elmvale Shopping Centre parking lot, west on Smyth Road, west on Saunderson Road, and south on Haig to Smyth Road. This section is 2.5 km long with an average speed of approximately 23 km/hr.

Section 2: Medium speed urban test section which starts at Haig and Smyth Road, continues south on Haig, east on Canterbury and south on Halifax to Dakota Avenue. This section is 2.4 km long, with an average speed of approximately 33 km/hr.

Section 3: Suburban test section which starts at the corner of Russell and Walkley Road, continues east on Walkley, north on Lancaster and north on Gladwin Crescent to Bourassa. This section is 2.5 km long with an average speed of approximately 48 km/hr.

Section 4: Highway test section going southbound on Russell Road from Ottawa City limits for approximately 2.4 km. This section represents a 2 lane undivided highway with a speed limit of 80 km/hr.

The drivers were instructed to drive with their usual habits while keeping within the speed limits.

Three different drivers were used for the testing. The number of test runs conducted by each test driver varied from one to three.

Testing on all four road sections was conducted during a test sequence, and the following procedure was utilized:

i) Drive the vehicle to test site. Ensure headlights on and all windows closed,

ii) Proceed to section #4 and accelerate vehicle to 80 km/hr. When test section is reached switch on DAS (one second mode for all tests),

iii) Drive vehicle along test section in normal manner observing all traffic signs,

iv) At end of section switch off DAS,

v) Repeat (ii) to (iv) for section #4 return,

vi) Drive vehicle to the start of section #3 and stop vehicle,

vii) Switch on DAS, wait 5 seconds and drive away,

viii) Drive vehicle along test section in normal manner observing all traffic signs,

ix) At end of section, stop vehicle, wait 5 seconds and switch off DAS,

x) Perform (vi) to (ix) for the following sections (#1 outbound, #2 outbound, #2 return, #1 return and #3 return),

xi) Return to Davis Engineering facilities and park vehicle in designated spot,

xii) With vehicle stopped, transmission in neutral, motor on (parking brake on) activate DAS for 30 seconds,

xiii) Remove bubble memory cartridge and turn over to data reduction facilities,

xiv) Record any pertinent details and/or anomalies.

A driver checklist/data sheet was used to record all pertinent details.

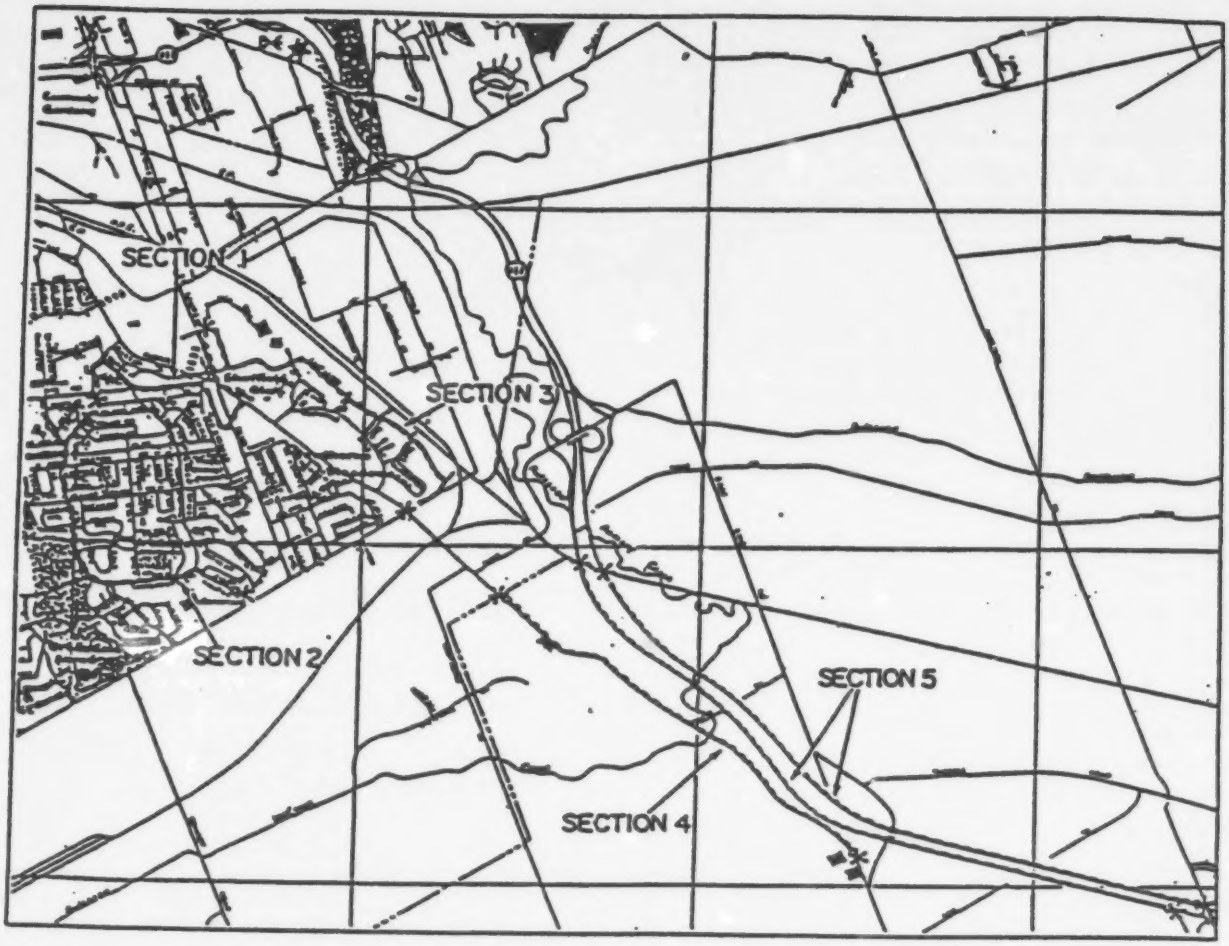

FIGURE 2.2
TYPICAL OPERATION TESTING
- FOUR ROAD SEGMENTS

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TABLE 5.1 TEST VEHICLE INFORMATION
CHECK SHEET

VEHICLE:	1985 Dodge Mini Ram Van					
BODY STYLE:	Van (Cargo)					
VIN:	1B7FK13C4FR103128					
TC #:	N/A	LICENCE #:	EVO2			
BUILD DATE:	7/84					

	TYPE	MANUFACTURER	MODEL NO.	SERIAL NO.		NAMEPLATE RATING
MOTOR:	GN 4B 21	BBC	8593791	P03	105V	162 AMP 2100 RPM
CONTROLLER:	FB	2001 R2	BBC			
CHARGER:	INTEGRATED INTO THE CONTROLLER					
BATTERY:	18 x 6 V LEAD-ACID 143 AH					
SYSTEM RATING:	15 kW NOMINAL, 28 kW PEAK (5 MIN)					
TRANSMISSION:	4 Speed Manual					
DRIVE:	Front Wheel Drive					
	RATIO (input-output)	- transaxle	3.56:1	- 3rd	1.21:1	
		- 1st	3.29:1	- 4th	0.88:1	
		- 2nd	1.89:1	- R	3.14:1	

TIRES:	MAKE:	Goodyear		
	SIZE:	P195/75R14 M + S		
	PRESSURE (psi):	FRONT: 35	REAR:	35
ROLLING RADIUS:	DYNAMOMETER	11.69 in	ON-ROAD	11.50 in
GVWR:	2300 lbs - Front	2430 lbs - Rear		

ACCUMULATED KILOMETERS:	When Received:	3890 km
	Start Testing:	5140 km
	Complete Testing:	5470 km
DYNAMOMETER TEST CONDITIONS:	Test Weight:	4500 lb *
	RLHP at 50 mph:	11.0 *

VEHICLE WEIGHT:	Empty:	LF:	878	RF:	924	F:	1802
		LR:	1208	RR:	1114	R:	2322
						TOTAL:	4124
	With Driver:	LF:	946	RF:	952	F:	1898
		LR:	1266	RR:	1118	R:	2384
						TOTAL:	4282

* Information obtained from MTC

TABLE 5.2/ VEHICLE OPERATION AND HANDLING CHECKLIST

Date: 85/6/25 Vehicle ID No. 103128 YCE878 Inspected by: Daniel Hsu

1. Manufacturer's Certification

   Check certification sticker on door. Present X missing _____

   Note any waivers from compliance with FMVSS N/A

2. Does electrical system follow accepted safe practices? Yes ____ No ____

   Explain: It is not yet accepted by Ontario Hydro inspection.

3. Can the vehicle be safely controlled throughout the entire speed range?
   Yes

4. During stopping do the brakes "pull"? No

5. Is there any motor overspeed protection? Yes

6. Is there any motor overheating protection? Yes

7. Is there any protection against going from a forward gear into reverse (or reverse into forward) while the vehicle is in motion? Yes

8. Can the vehicle be operated when the charger is plugged in? No

9. Is it dangerous to operate the brake and acceleration simultaneously?

10. Can the vehicle be started when the accelerator is engaged? No

TABLE 5.2/Vehicle Operation and Handling
Checklist (continued)

11. Can gears be downshifted without danger of controller shutdown? Yes

12. Identify all starter or operating interlocks.

The vehicle cannot be operated if the charger plug is not plugged in the receptacle under the hood.

The vehicle cannot be started if the accelerator is engaged.

The vehicle cannot be started if the emergency button is engaged. Activating the emergency button while the vehicle is in motion will automatically shut down the controller and cause a loss of traction power.

TABLE 6.1

TYPICAL OPERATION TESTING (JUNE 16, 1986)
MEASURED VEHICLE TRACTIVE ENERGY VS
ESTIMATED VEHICLE TRACTIVE ENERGY

Run Serial No.	Segment No.	Measured Vehicle Tractive Energy kJ		Estimated Vehicle Tractive Energy kJ		*Variation %	
		Consumption	Regeneration	Consumption	Regeneration	Pos.	Reg.
JUN1705.DAT	1 out	1171.5	618.8	1268.8	470.3	108	76
08	1 ret	650.1	806.0	885.4	519.4	136	66
06	2 out	1451.8	922.1	1524.3	652.5	105	71
07	2 ret	1358.0	916.4	1480.6	667.0	109	73
04	3 out	1170.6	377.5	1041.8	381.0	89	101
09	3 ret	1414.4	523.6	1541.1	413.8	109	76
02	4 out	1315.9	0.0	1522.0	0.1	116	0
03	4 ret	1895.0	32.7	1361.6	21.2	72	65
AVE		1303.5	524.7	1328	390.7	102	74

* Variation = Estimated/Measured

TABLE 6.2a

DAVIS STEADY STATE TESTING
ENERGY CONSUMPTION RESULTS SUMMARY

Date (yy/mm/dd)	Temp. (°C)	Speed (km/hr)	Gear	Battery Output (kW)	Energy ** Consumption (kJ/km)
860304	-1	38.8	2	5.431	504
05	-4	75.9	3	16.855	799
		57.9	3	9.647	600
22	02	19.9	1	3.737	676
		38.4	2	6.412	601
		38.5	1	6.294	589
		58.1	3	10.595	657
		57.9	2	10.946	681
*860325	-4	56.7	3	10.052	638
* 26	+16	57.1	3	8.763	553
* 27	+8	56.4	3	8.708	556

* Constant velocity range test

** Based on average of first 35 cycles.

TABLE 6.2b

MTC STEADY STATE TESTING
ENERGY CONSUMPTION RESULTS SUMMARY

Date (yy/mm/dd)	Temp. (°C)	Speed (km/hr)	Gear	Battery Output (kW)	Energy Consumption (kJ/km)
(after alignment)					
850820	21	76.4	2/3	15.5	730
		68.4	2	10.9	574
		59.4	2	7.9	479
		48.8	1/2	6.2	457
		39.7	2/3	4.7	426
(before alignment)					
850718	25	80.0	4	15.55	700
		64.0	3	9.93	559
		48.0	2	6.43	482
		32.0	1	4.60	518

TABLE 6.2c

DAVIS TYPICAL OPERATION ON-ROAD TESTING
RESULTS SUMMARY

	Segment 1	Segment 2	Segment 3	Segment 4
Distance (km)	17.7	23.9	25.1	26.1
Average Speed (km/hr)	21.7	30.5	39.4	74.8
Average Battery Energy (kJ)				
- Consumed	2202	3064	2236	2357
- Regenerated	270	375	183	12
Average Net Energy (kJ/km)	1038	1119	818	902

TABLE 6.2d

MTC ON-ROAD TEST
RESULTS SUMMARY

	Route 1	Route 2
	East Bldg. - Hwy. 401 Avenue Rd. - Queen's Park Circle - Bay St. - Government Garage	East Bldg. - Wilson Ave. - Avenue Rd. - Queen's Park Circle - Bay St. Government Garage
Time (min)	N/A	71
Distance (km)	31.6	31.1
Average Trip Speed (km/hr)	N/A	26.3
Vehicle Payload (kg)	150	240
Test Vehicle Weight (kg)	1945	2035
Battery Output (kW-hr)	7.49	8.84
(kJ)	27,000	31,800
Input to Battery (kW-hr)	0.85	1.09
(kJ)	3,100	3,900
Net Energy Consumption (kJ/km)	756	1023

TABLE 6.2e

DAVIS DYNAMOMETER TESTING
TEST PARAMETERS

Vehicle Curb Weight:		1875 kg
Vehicle Payload:		71 kg
Test Vehicle Weight:		1946 kg
Tire Pressure:	Front:	45 psi
	Rear:	35 psi
Ambient Temperature:	39D04.DAT:	22.7°C
	39D05.DAT:	24.5°C
	39D06.DAT:	25.7°C
Dynamometer Inertia:		1991 kg
Dynamometer Power:		8.806 kW

TABLE 6.2f

DAVIS DYNAMOMETER TESTING
ENERGY CONSUMPTION RESULTS SUMMARY
SAE J227A SCHEDULE C

Serial # (km/hr)	Avg. Speed (km/hr)	Distance (km)	Battery Energy (kJ)		Tractive Energy (kJ)		Net * Energy Consumption (kJ/km)
			Con.	Reg.	Con.	Reg.	
39D04.DAT	24.96	20.63	15992	1110	11711	4434	721.50
39D05.DAT	23.43	20.27	15798	1169	11070	4749	721.69
39D06.DAT	23.02	20.51	16262	1356	11413	4867	726.90

* Based on 35 cycle average.

TABLE 6.2g

MTC DYNAMOMETER TESTING
TEST PARAMETERS

Vehicle Curb Weight:	1795 kg
Vehicle Payload:	238 kg
Test Vehicle Weight:	2033 kg
Tire Pressure:	Front: 45 psi Rear: 35 psi
Ambient Temperature:	25°C
Dynamometer Inertia:	2042 kg
Dynamometer Power:	8.206 kW

TABLE 6.2h

MTC DYNAMOMETER TESTING
ENERGY CONSUMPTION RESULTS SUMMARY
SAE J227A SCHEDULE C

	Nominal Acceleration Time
Cut-off Criteria	+2 s
Number of Cycles Completed	64
Distance (km)	35.11
Battery Output (kJ)	34240
Battery Discharge (%)	68.4%
Net Energy Consumption (kJ/km)	975

TABLE 6.3a

SUMMARY OF RANGE TEST DATA ON EV02 - CONDUCTED BY DAVIS ENGINEERING

Test no.	1	2	3	39D04.DAT	39D04.DAT	39D04.DAT
Test identification	56 km/hr constant	56 km/hr constant	56 km/hr constant	SAE J227a C Cycle	SAE J227a C Cycle	SAE J227a C Cycle
Range (km)	60.9	74.1	74.6	20.63	20.27	20.51
Number of cycle	--	--	--	35	35	35
Total energy consumed						
- dc kWh discharge	10.870	11.430	11.610	4.442	4.388	4.517
- dc kJ discharge	39132	41148	41796			
Net energy consumption (kJ/km)	643	555	560			
- dc energy consumption (Wh/cycle)	--	--	--	127	125	129
- dc energy consumption (Wh/km)	179	154	156	215	217	220
Battery discharge* (%)	72.4	75.3	76.5			
Temp. ambient	-4°C	16°C	8°C	22.7°C	24.5°C	25.7°C

* Based on battery capacity of 143 AH

TABLE 6.3b

SUMMARY OF RANGE TEST DATA ON EV02 - CONDUCTED BY MTC

Date	85 09 06	85 09 12	86 08 11	86 08 15	86 08 18	86 08 25	86 11 14	86 11 18
Test identification	SAE J227a C Cycle	56 km/hr constant	56 km/hr constant	60 km/hr constant	56 km/hr constant	56 km/hr constant	SAE J227a C Cycle	SAE J227a C Cycle
Range (km)	35.1	81.4	65.2	66.0	65.4	65.9	16.5	22.4
Number of cycles	64	--	--	--	--	--	30	39
Total energy consumed								
- dc kWh discharge	9.510	11.740	9.386	9.770	9.222	9.068	4.518	5.307
- dc kJ discharge	--	42264	33790	35172	33199	32645	--	--
- dc Ah discharge	97.79	113.80	80.76	94.41	89.18	87.84	45.87	50.08
Net energy consumption (kJ/km)	--	519	518	533	508	495	--	--
- dc energy consumption (Wh/cycle)	149	--	--	--	--	--	151	136
- dc energy consumption (Wh/km)	271	144	148	215	141	138	274	237

TABLE 6.3c

SUMMARY OF RANGE TEST DATA ON EV01 - CONDUCTED BY MTC
Vehicle had been Soaked in Room Temp. 22°C

Date	86 11 04 *	86 11 05	86 11 12
Test identification	SAE J227a C Cycle	56 km/hr constant	SAE J227a C Cycle
Range (km)	20.9	72.1	25.9
Number of cycles	38	--	45
Total energy consumed			
- dc kWh discharge	5.132	10.022	6.075
- dc kJ discharge	--	36079	--
- dc Ah discharge	52.44	93.90	61.78
Net energy consumption (kJ/km)	--	500	--
- dc energy consumption (Wh/cycle)	135	--	141
- dc energy consumption (Wh/km)	246	139	235

* Charger was not operating effectively

TABLE 6.3d

SUMMARY OF RANGE TEST DATA ON EV01 - CONDUCTED BY MTC
Vehicle had been Soaked in Room Temp. at -15°C

Date	86 11 25	86 11 26	86 12 16	86 12 17
Test identification	SAE J227a C Cycle	56 km/hr constant	SAE J227a C Cycle	56 km/hr constant
Range (km)	25.5	64.2	24.8	65.0
Number of cycles	43	--	43	--
Total energy consumed				
- dc kWh discharge	6.162	9.178	6.228	9.364
- dc kJ discharge	--	33041	--	33710
- dc Ah discharge	63.62	85.79	64.45	89.59
Net energy consumption (kJ/km)	--	515	--	519
- dc energy consumption (Wh/cycle)	143	--	145	--
- dc energy consumption (Wh/km)	241	143	249	144

TABLE 6.4a

ACCELERATION/BRAKING

Top Speed (km/hr)	30	40	50	60	70	80
Acceleration Time (sec)	7	11	16	24	35	48
Acceleration Time (sec) W/Battery 80% Discharged	--	--	58	--	--	--
Final Gear Position	1	2	3	3	3	4
Pavement Braking Distance (m)	10	16	25	--	--	--

TABLE 6.4b

GRADEABILITY

Speed (km/hr)	20	30	40	50	60	70	80
Gear Position	1	1	2	2	3	3	4
Acceleration (m/sec^2)	1.40	1.02	.76	.60	.51	.40	.22
Gradeability (%)	14.4	10.4	7.3	6.1	5.2	4.1	2.3

TABLE 6.5a

VEHICLE EFFICIENCY SUMMARY

Dynamometer:	Consumption	- 74.5%
	Regeneration	- 23.7%
On Road:	Consumption	- 67.3%
	Regeneration	- 22.3%
Mean Charger Efficiency		- 77.8%
Mean Battery Charge Efficiency		- 76.5%

TABLE 6.5b

BATTERY CHARGING EFFICIENCY

	Input to Battery	Output from Battery	Output from AC Line	Charging Efficiency: Charger from AC to DC	Charging Efficiency: Battery from Output to Input	Total Output Efficiency
1	125.5 AH 15.12 KWH	123.1 AH 11.63 KWH	19.5 KWH	77.5%	76.9%	59.6%
2	130.0 AH 15.61 KWH	125.8 AH 11.89 KWH	20.0 KWH	78.1%	76.1%	59.4%
	MEAN			77.8%	76.5%	59.5%

TABLE 6.6

GASOLINE POWERED PLYMOUTH VOYAGER
DYNAMOMETER TEST RESULTS

Make/Year	1985 Plymouth Voyager
Dynamometer Inertion	1,136 kg
Dynamometer Power	6.935 kW

Test Type	Temp. (°C)	Average Speed (km/hr)	Fuel Consumption (l/100 km)	Net Energy Consumption (kJ/km)
UDDS	25.0	35.5	10.6	3392
HWFCT	28.0	76.5	7.6	2432
*S.S.-1	31.0	100.0	8.2	2624
*S.S.-1	33.0	125.0	11.4	3648
UDDS	26.0	35.5	10.5	3360
HWFCT	28.0	76.5	7.9	2528
*S.S.-1	29.0	100.0	8.3	2656
*S.S.-1	30.0	125.0	11.5	3680

* Steady State Tests

TABLE 8.1

LEAD ACID VS SODIUM SULPHUR (B06)

CHARACTERISTIC	LEAD ACID	SODIUM SULPHUR
RANGE		
- constant 56 km/hr	81 km	209 km
- SAE J227a C cycle	35 km	85 km
ACCELERATION		
- at full charge	16 sec	16 sec
- at 80% depth of discharge	58 sec	17.2 sec
MAXIMUM SPEED		
- level road	95 km/hr	95 km/hr
- 10% grade	30 km/hr	30 km/hr
ENERGY CONSUMPTION		
- constant 56 km/hr	144 Wh/km	157 Wh/km *
- SAE J227a C cycle	237 Wh/km	236 Wh/km
OPERATING TEMPERATURE	20°C	300 - 350°C
MAINTENANCE	Weekly cell watering	None
GAS PRODUCTION	Hydrogen	None
EFFECT OF DEEP DISCHARGE (100%)	Reduced battery life	None
EFFECT OF HIGH RATE OF CHARGE	Reduced battery life	None
EFFECT OF PROLONGED IDLE PERIOD (at full discharge)	Reduced battery capacity	None
EFFECT OF PROLONGED IDLE PERIOD WITHOUT POWER SUPPLY (battery at full charge)	None	Battery "freezes" in 1-2 weeks.

* Thermal management was manually controlled, consequently energy may have been lost during the test.

APPENDIX IV

- LIST OF FIGURES -

FIGURE 6.1a ROAD LOAD POWER VS VEHICLE SPEED

FIGURE 6.1b ESTIMATED VEHICLE ROAD LOAD POWER
AND MEASURED VEHICLE ROAD LOAD POWER VS TIME
TEST SEGMENT 2

FIGURE 6.2a ENERGY CONSUMPTION VS CONSTANT SPEED
STEADY STATE TESTS

FIGURE 6.2b TYPICAL OPERATION TESTING
FOUR ROAD SEGMENTS

FIGURE 6.2c TEST RUN CYCLE (MTC)

FIGURE 6.2d TYPICAL OPERATION
BATTERY POWER AND VEHICLE SPEED VS TIME
TEST SEGMENT 1

FIGURE 6.2e TYPICAL OPERATION
BATTERY POWER AND VEHICLE SPEED VS TIME
TEST SEGMENT 2

FIGURE 6.2f TYPICAL OPERATION
BATTERY POWER AND VEHICLE SPEED VS TIME
TEST SEGMENT 3

FIGURE 6.2g TYPICAL OPERATION
BATTERY POWER AND VEHICLE SPEED VS TIME
TEST SEGMENT 4

FIGURE 6.2h STANDARD TEST CYCLE
SAE RECOMMENDED PRACTICE J227a
SCHEDULE C

APPENDIX IV

- LIST OF FIGURES -

FIGURE 6.5a TYPICAL OPERATION TESTING
VEHICLE ROAD LOAD POWER VS BATTERY POWER
TEST SEGMENT 1

FIGURE 6.5b TYPICAL OPERATION TESTING
VEHICLE ROAD LOAD POWER VS BATTERY POWER
TEST SEGMENT 2

FIGURE 6.5c TYPICAL OPERATION TESTING
VEHICLE ROAD LOAD POWER VS BATTERY POWER
TEST SEGMENT 3

FIGURE 6.5d TYPICAL OPERATION TESTING
VEHICLE ROAD LOAD POWER VS BATTERY POWER
TEST SEGMENT 4

FIGURE 6.5e DYNAMOMETER TESTING
VEHICLE ROAD LOAD POWER VS BATTERY POWER
LINES OF BEST FIT
39D04.DAT

FIGURE 8.1 VEHICLE ACCELERATION AT FULL CHARGE
AND 80% DEPTH OF DISCHARGE

FIGURE 8.2 VEHICLE RANGE VS DEPTH OF DISCHARGE
CONSTANT 56 KM/HR AND SAE J227A C CYCLE

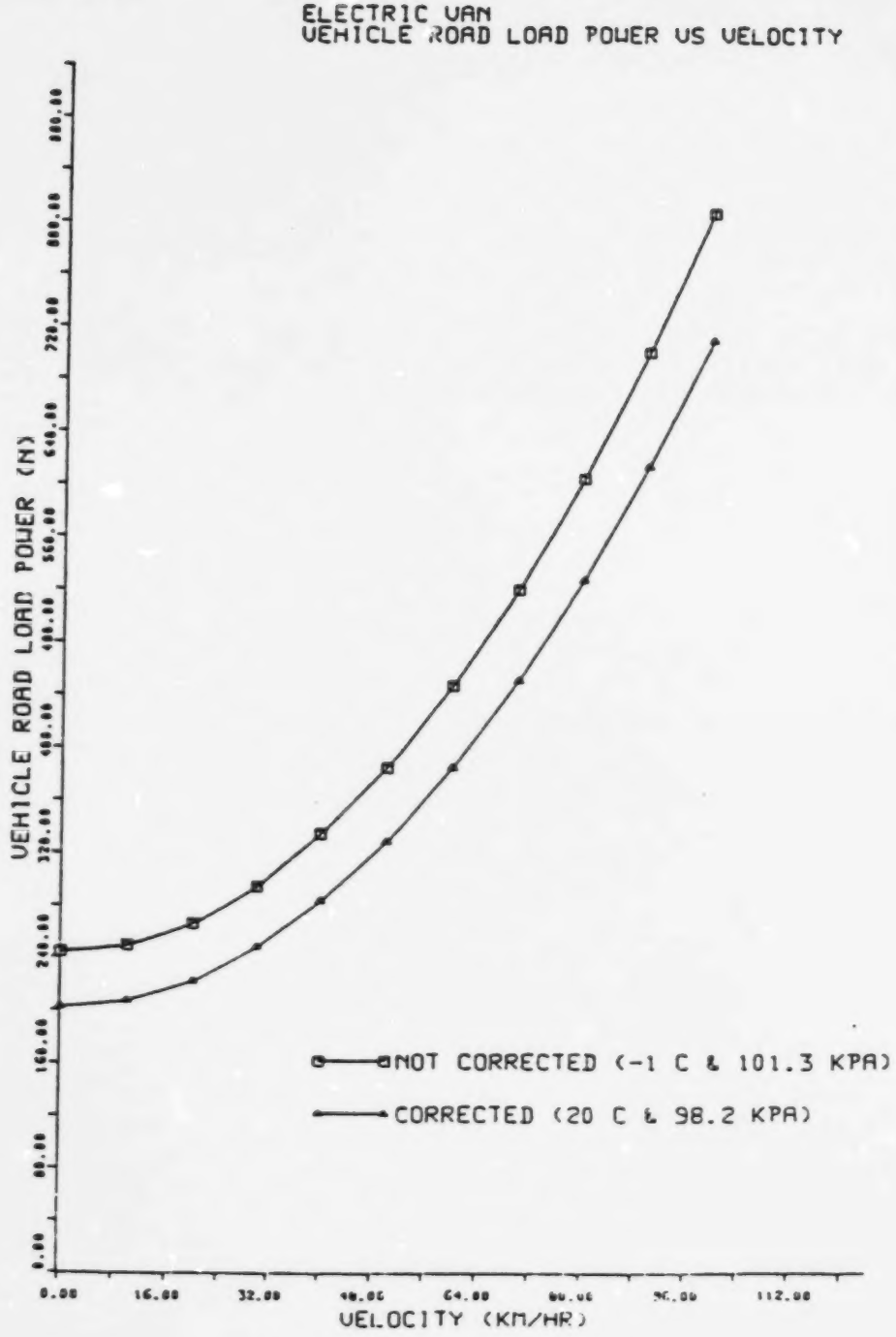

ELECTRIC VAN
VEHICLE ROAD LOAD POWER VS VELOCITY
VEHICLE ROAD LOAD POWER (N)
VELOCITY (KM/HR)
NOT CORRECTED (-1 C & 101.3 KPA)
CORRECTED (20 C & 98.2 KPA)

FIGURE 6.1a
ROAD LOAD POWER VS VEHICLE SPEED

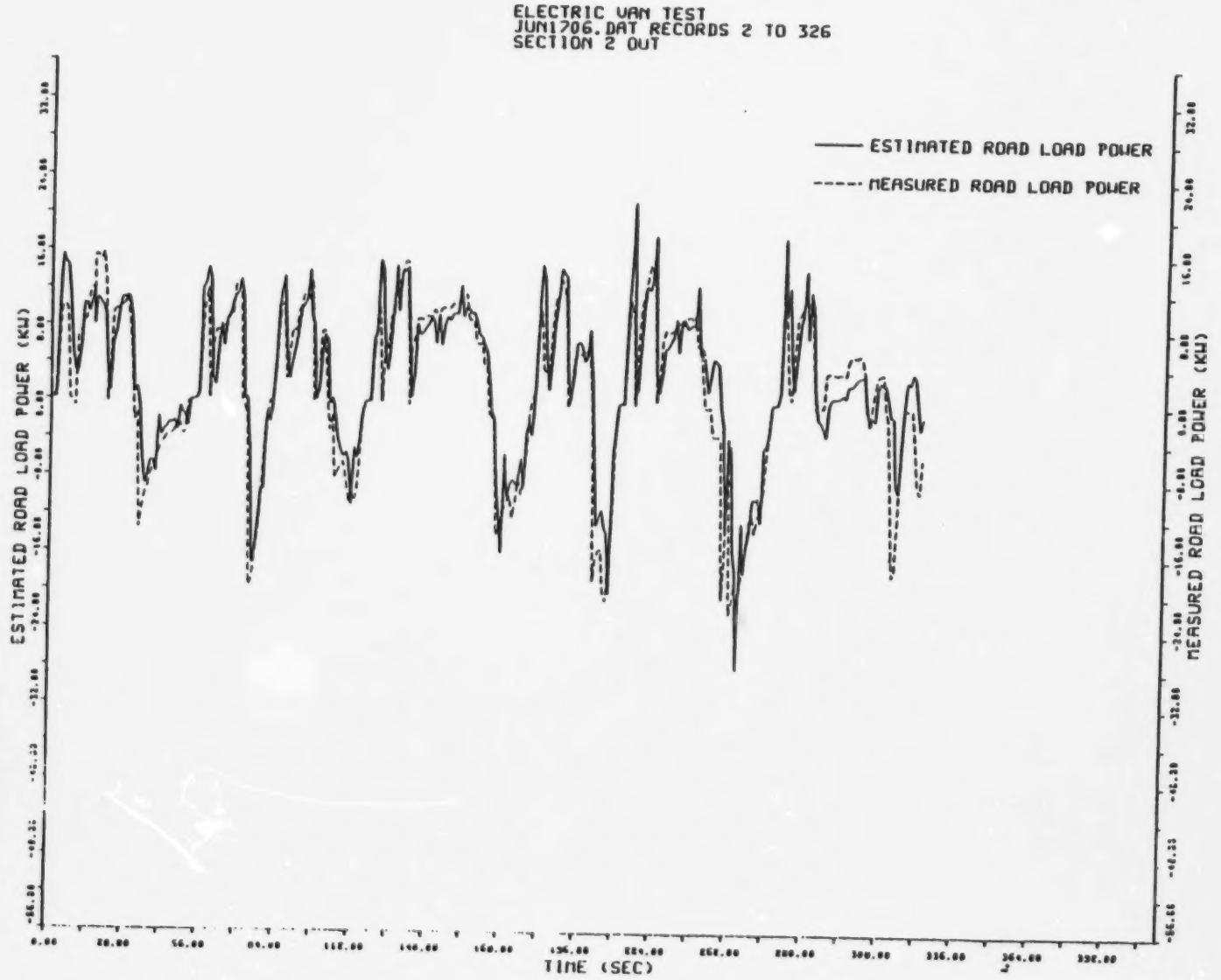


FIGURE 6.1b

ESTIMATED VEHICLE ROAD LOAD POWER AND MEASURED VEHICLE ROAD LOAD POWER VS TIME
TEST SEGMENT 2

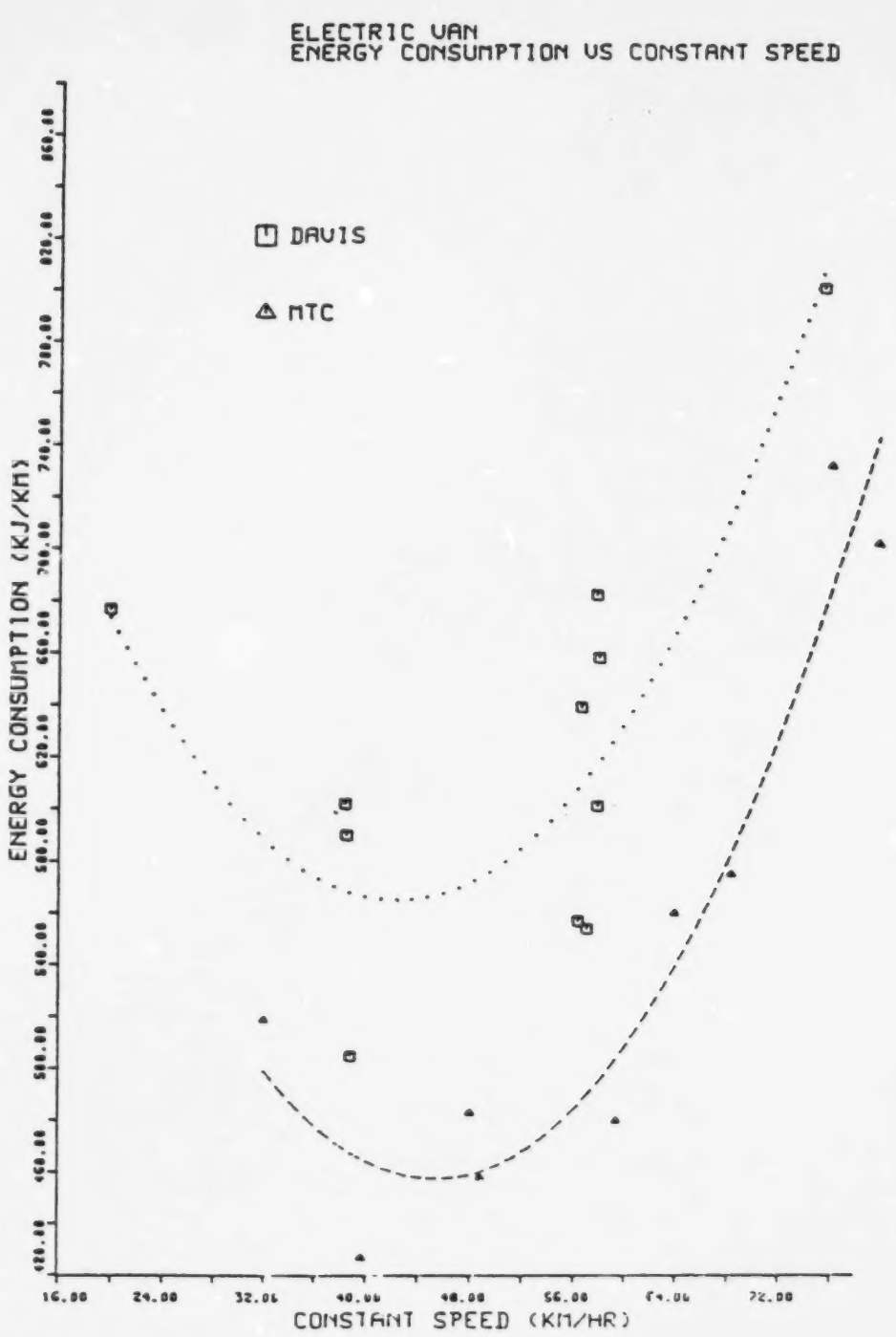


FIGURE 6.2a
ENERGY CONSUMPTION VS CONSTANT SPEED
STEADY STATE TESTS

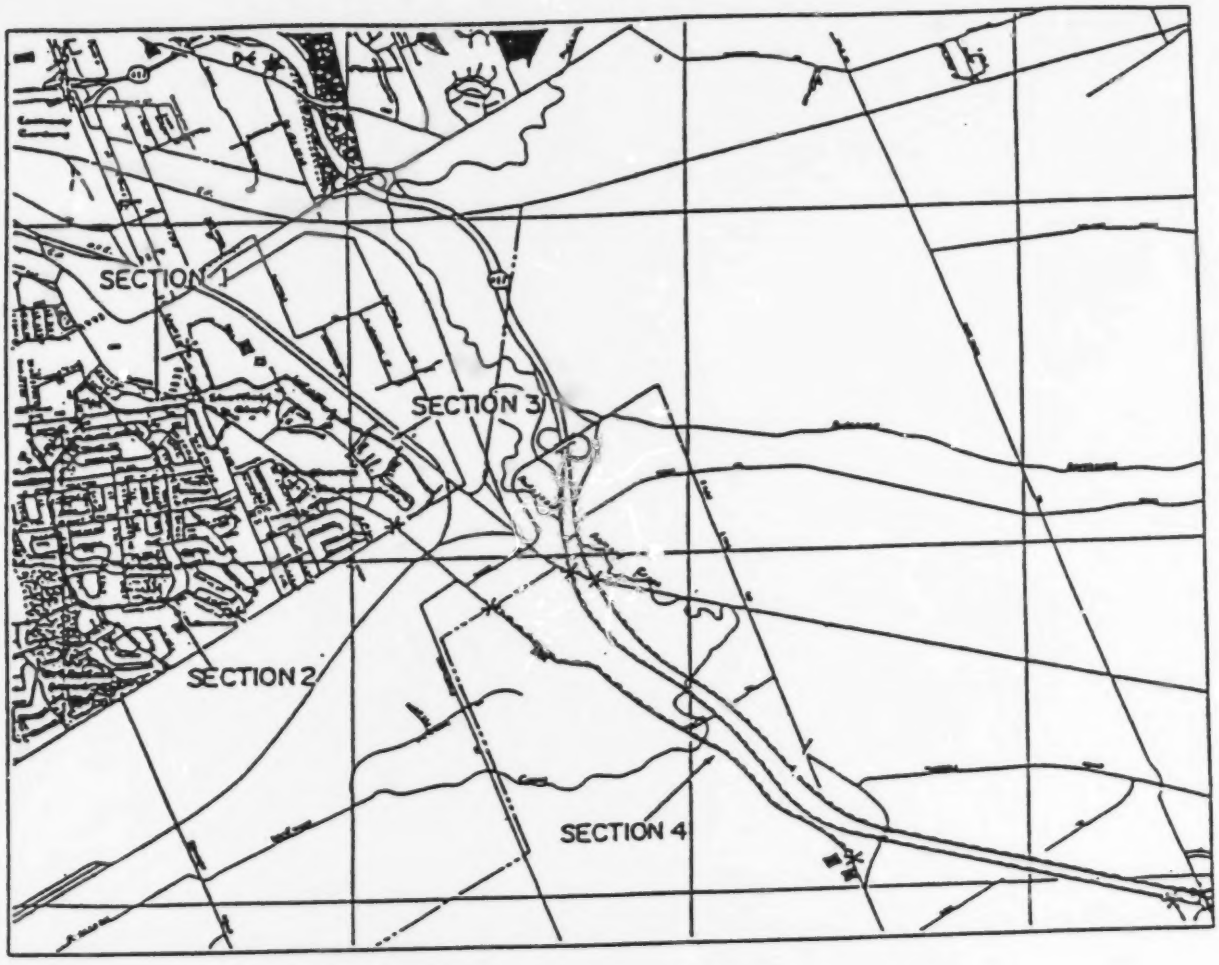


FIGURE 6.2b

TYPICAL OPERATION TESTING
- FOUR ROAD SEGMENTS

(DAVIS ENGINEERING LTD.)

FIGURE 6.2c

TEST RUN CYCLE (MTC)

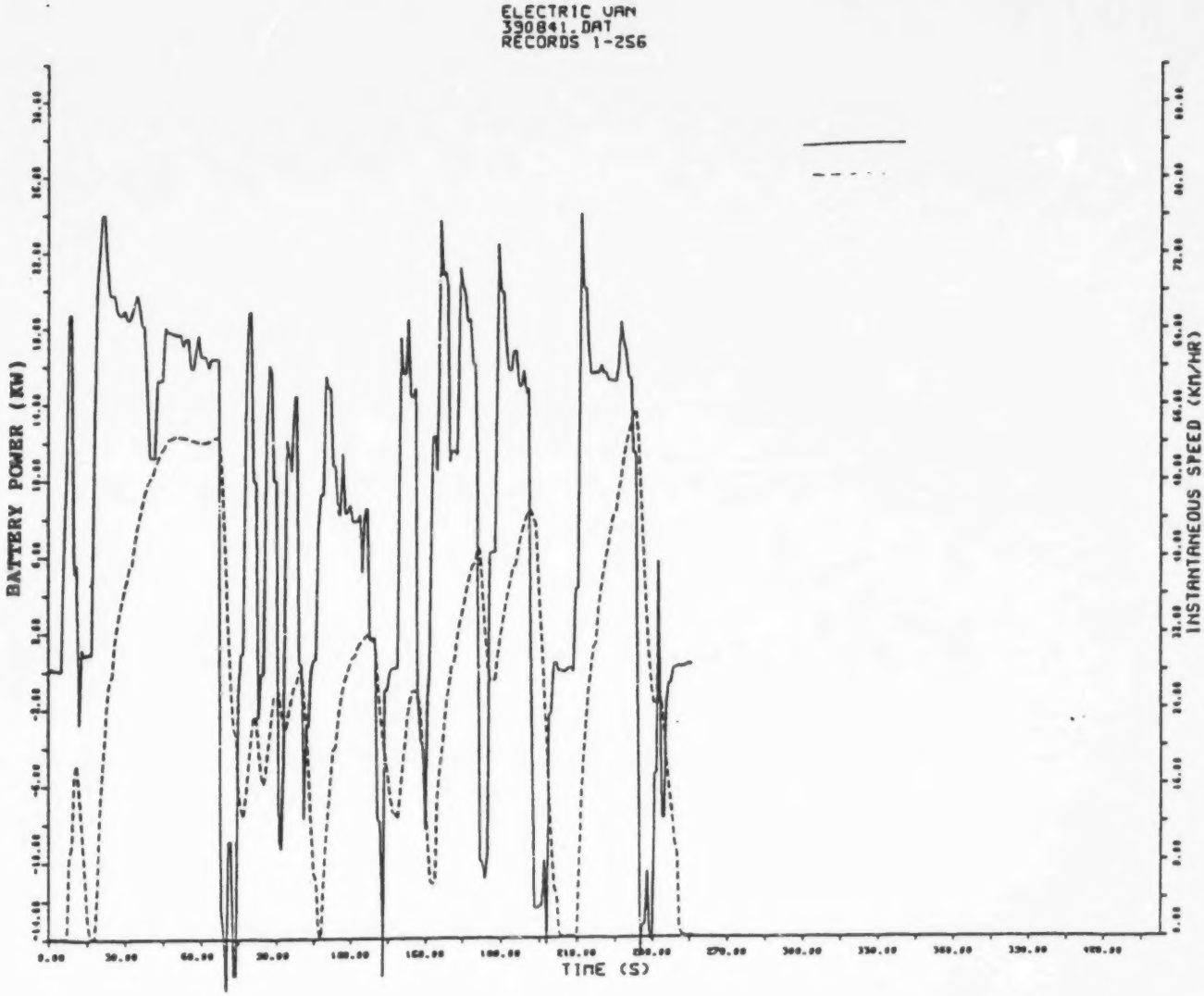


FIGURE 6.2d

TYPICAL OPERATION
BATTERY POWER AND VEHICLE SPEED VS TIME
TEST SEGMENT 1

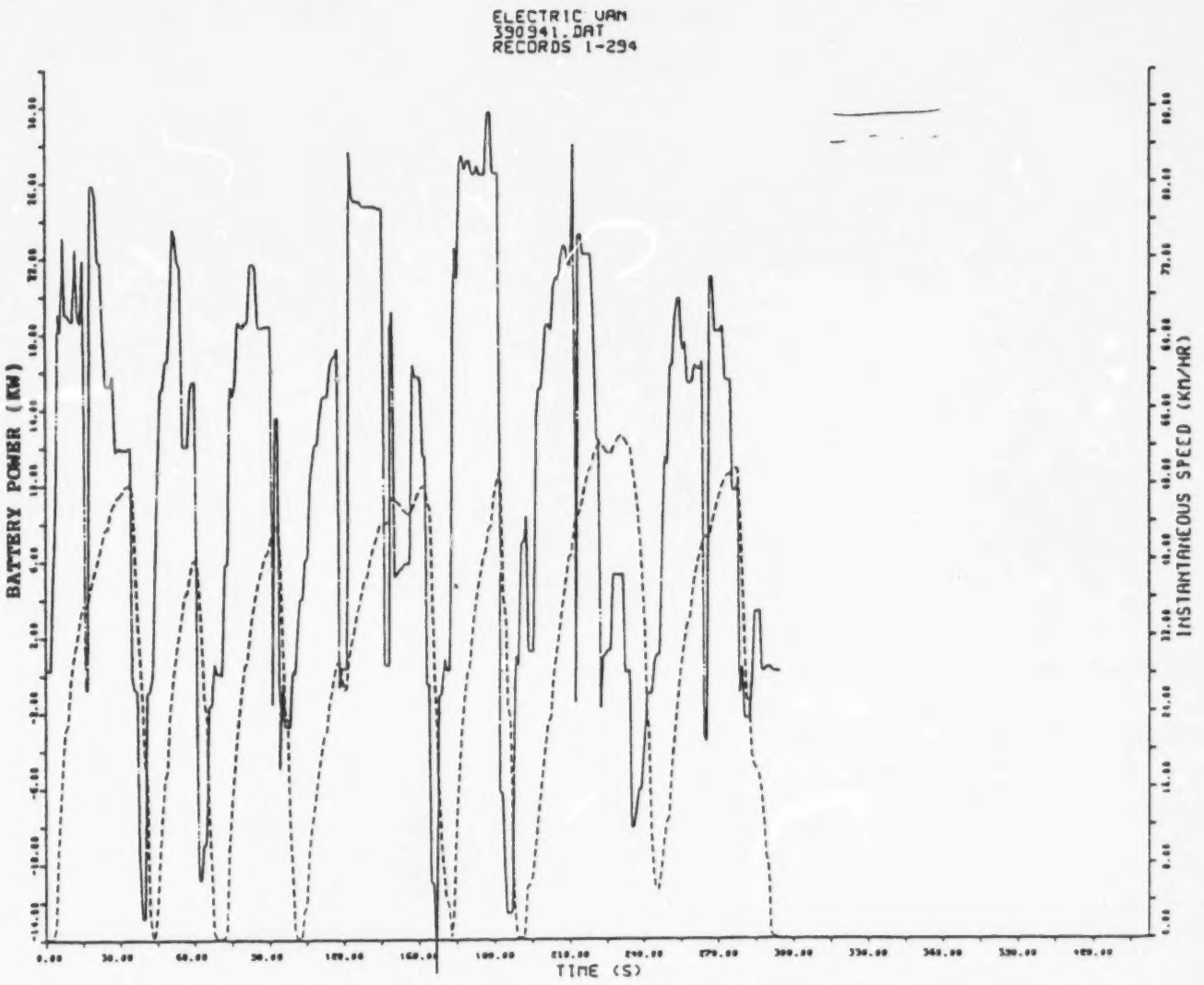


FIGURE 6.2e
TYPICAL OPERATION
BATTERY POWER AND VEHICLE SPEED VS TIME
TEST SEGMENT 2

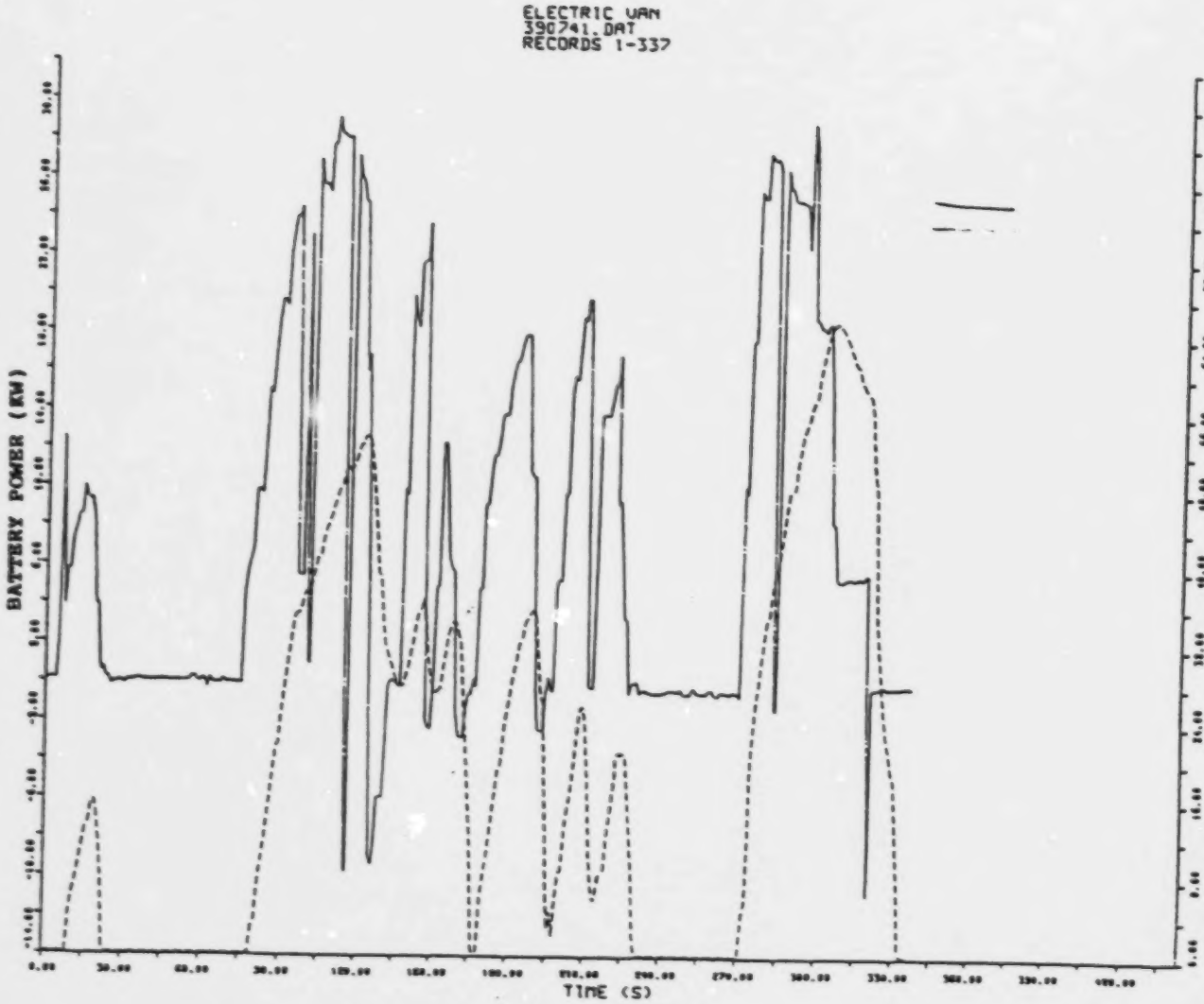


FIGURE 6.2f

TYPICAL OPERATION
BATTERY POWER AND VEHICLE SPEED VS TIME
TEST SEGMENT 3

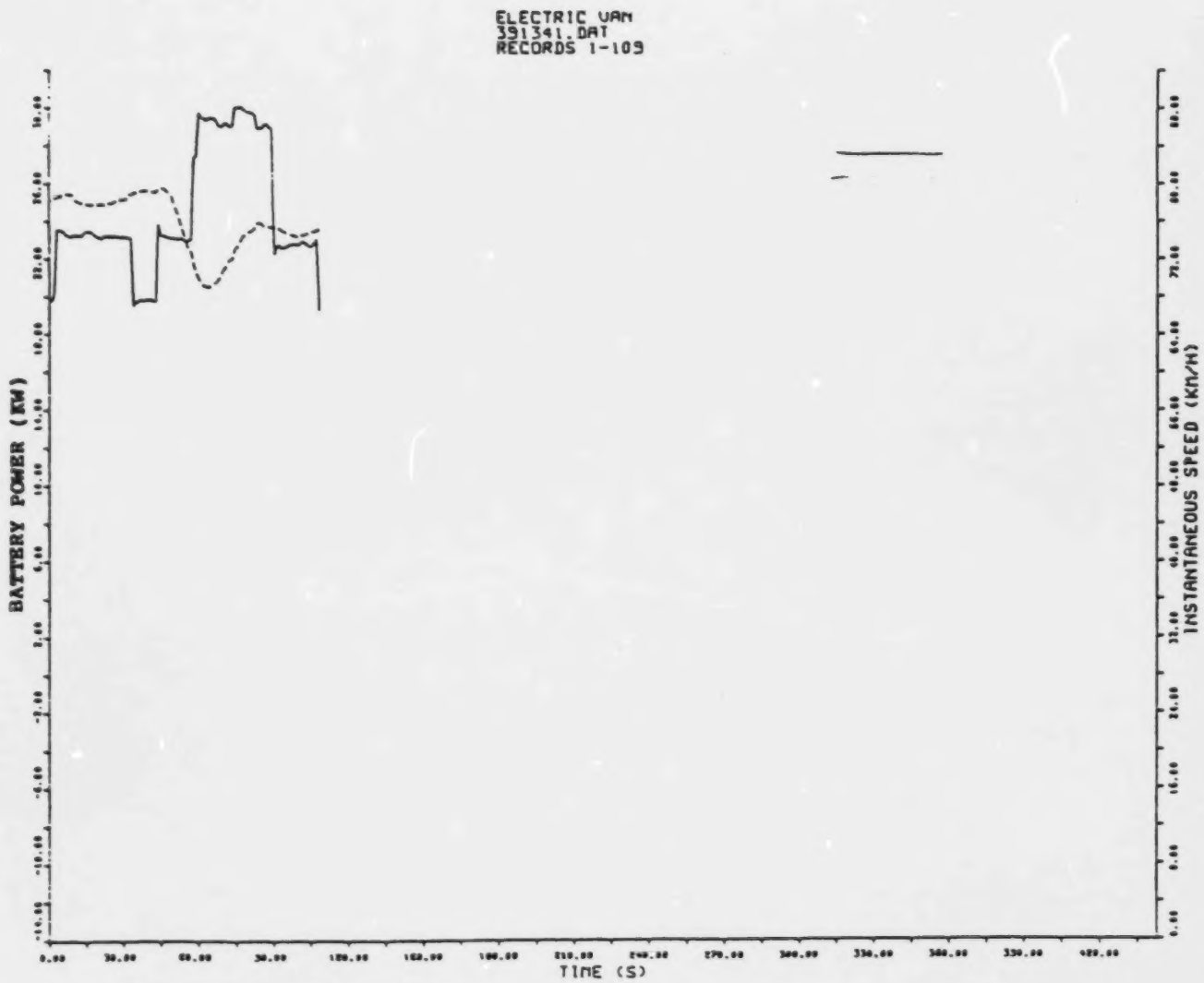


FIGURE 6.2g

TYPICAL OPERATION

BATTERY POWER AND VEHICLE SPEED VS TIME

TEST SEGMENT 4

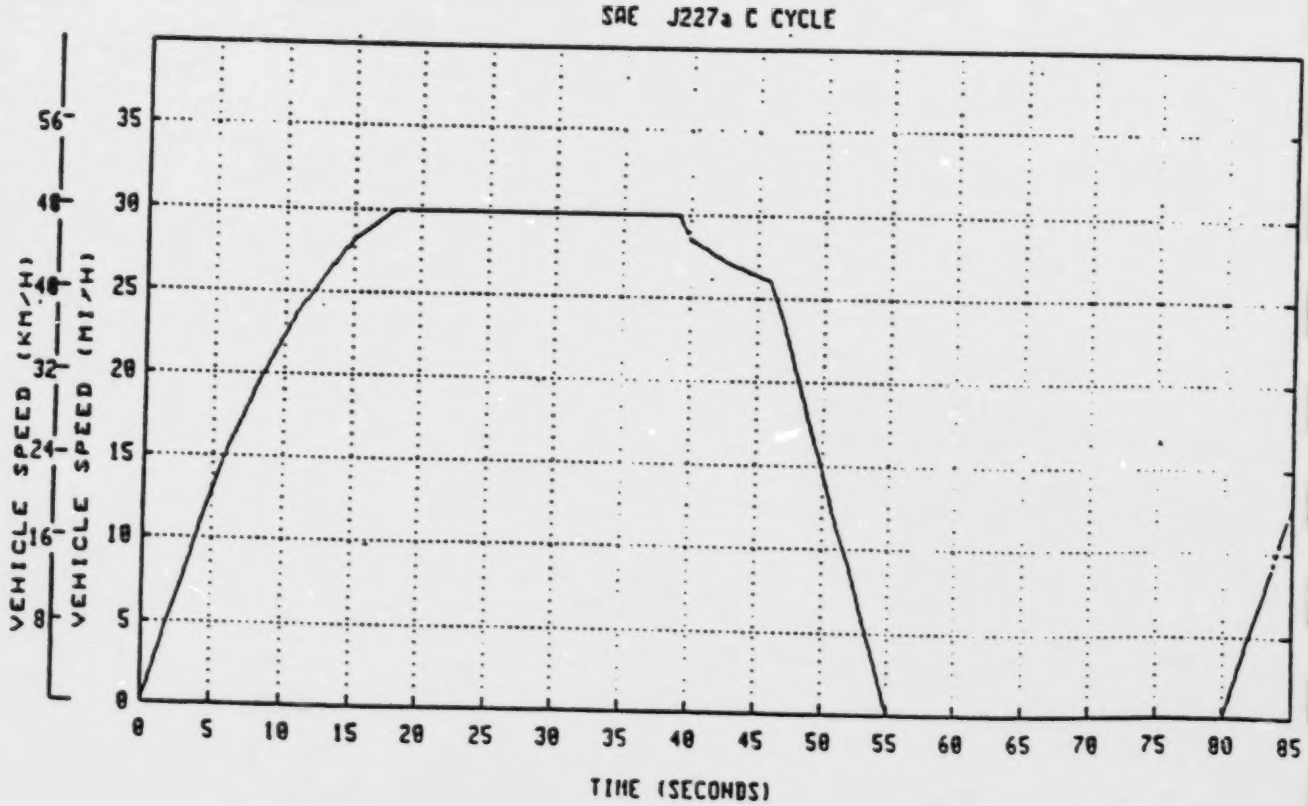


FIGURE 6.2h

STANDARD TEST CYCLE
- SAE RECOMMENDED PRACTICE J227a
- SCHEDULE C

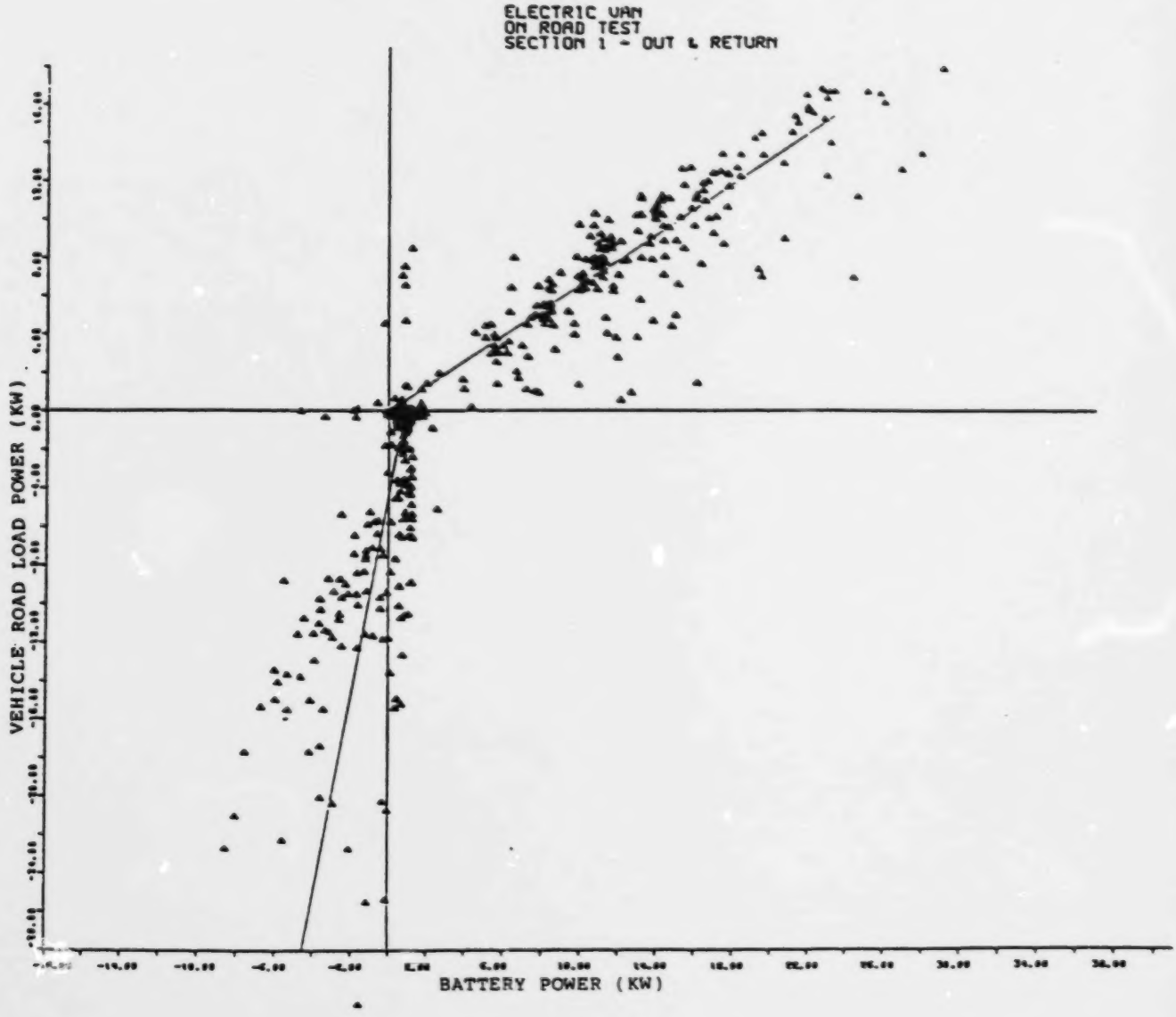


FIGURE 6.5a

TYPICAL OPERATION TESTING
VEHICLE ROAD LOAD POWER VS BATTERY POWER
TEST SEGMENT 1

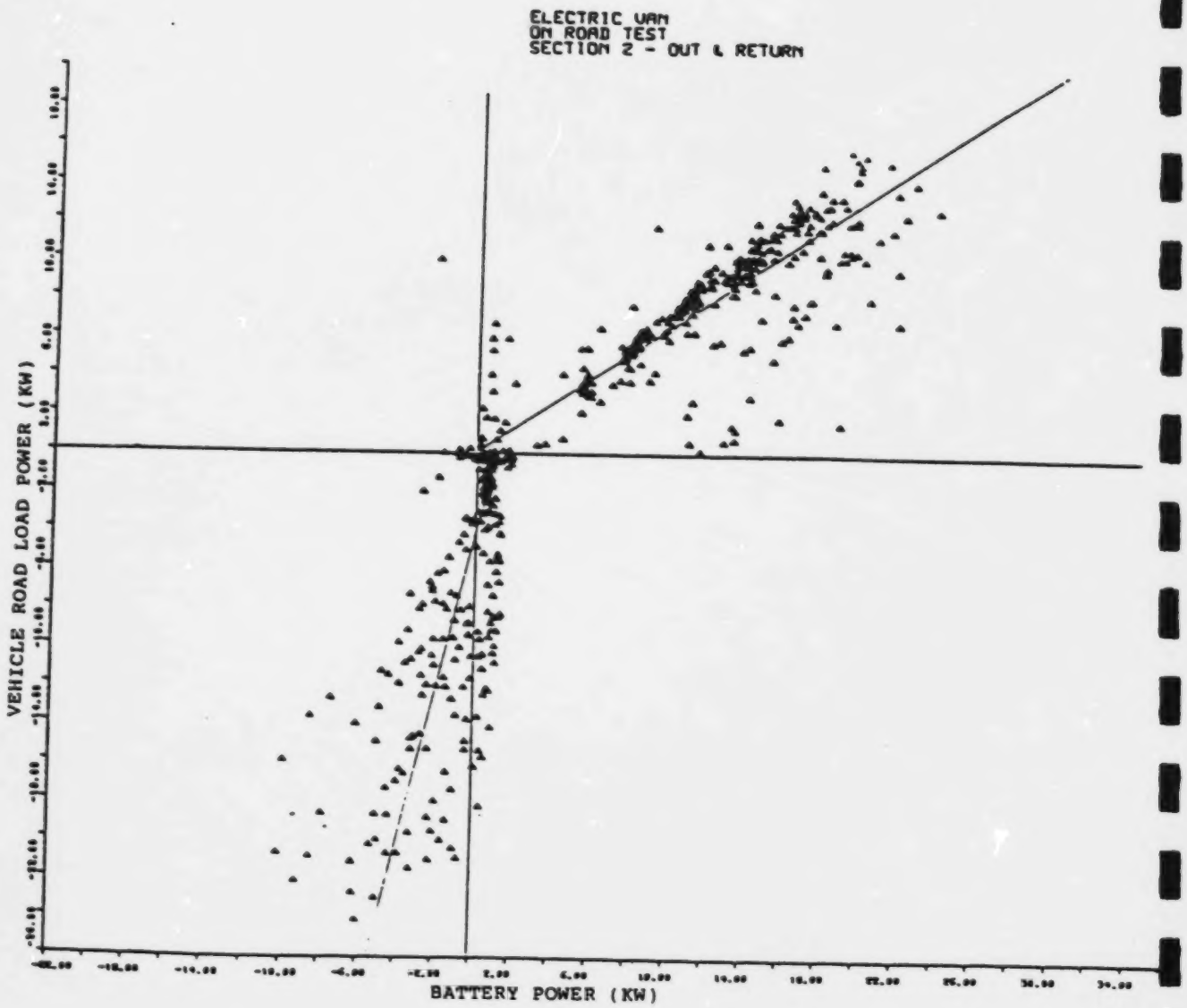


FIGURE 6.5b
TYPICAL OPERATION TESTING
VEHICLE ROAD LOAD POWER VS BATTERY POWER
TEST SEGMENT 2

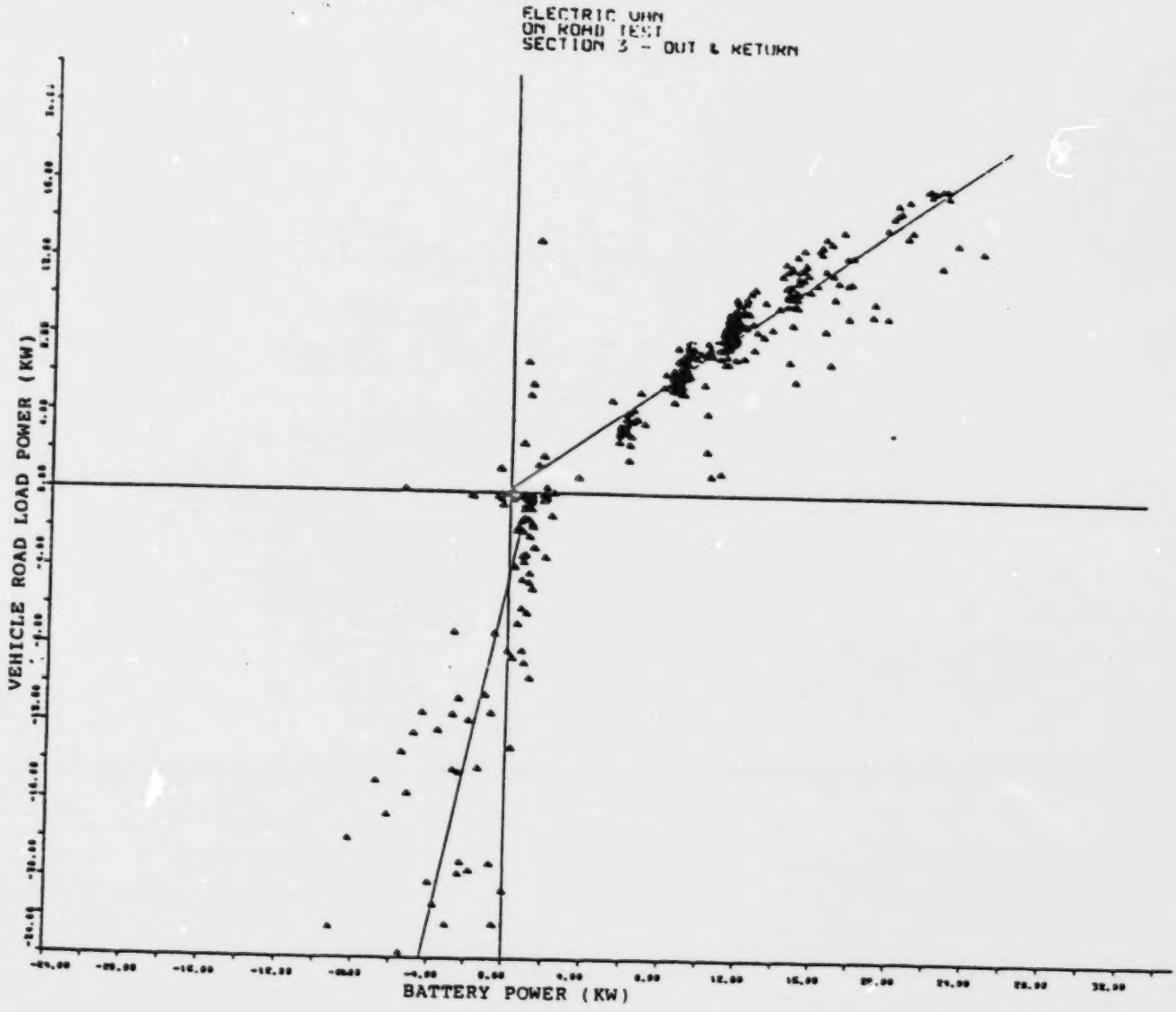


FIGURE 6.5c

TYPICAL OPERATION TESTING
VEHICLE ROAD LOAD POWER VS BATTERY POWER
TEST SEGMENT 3

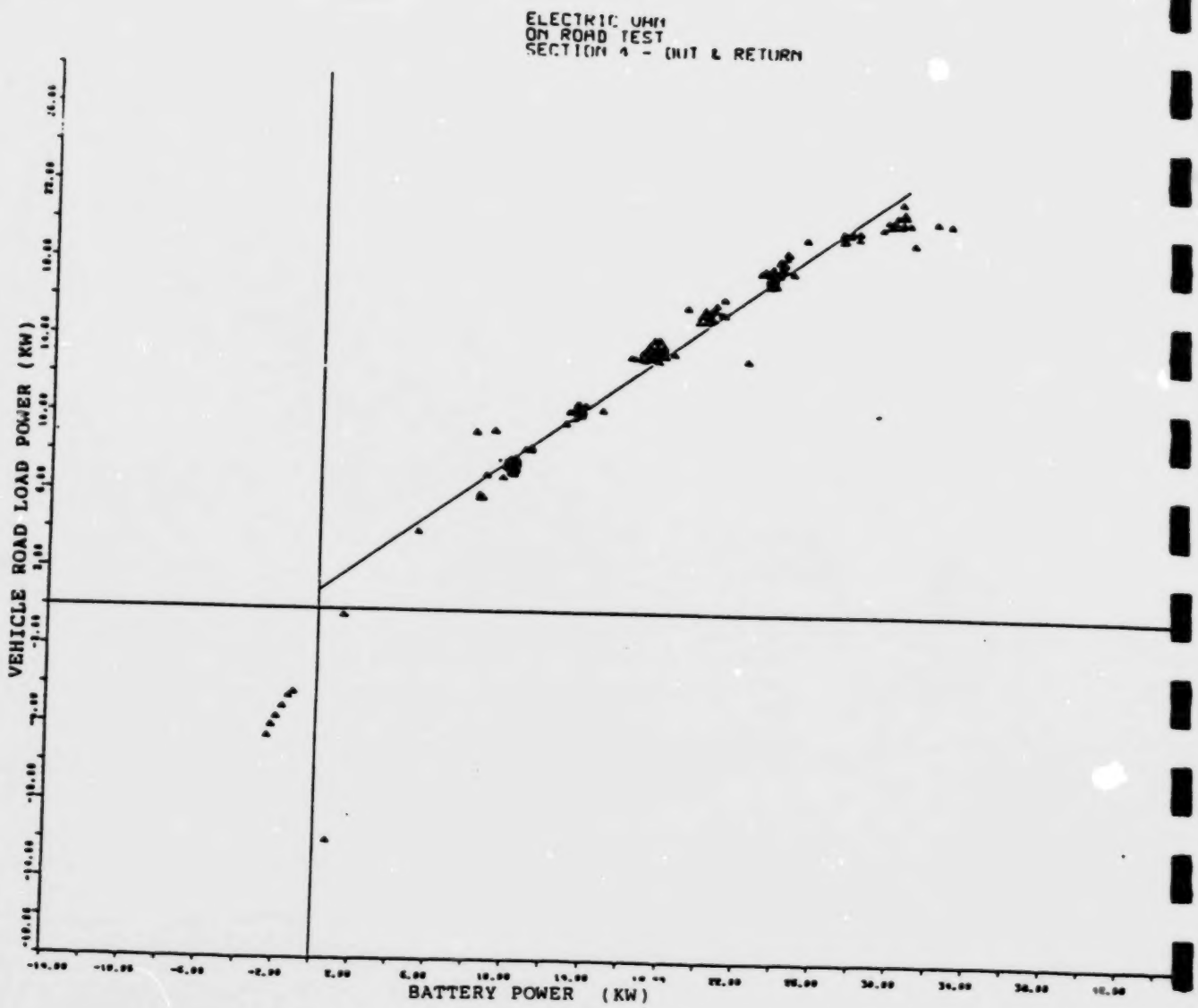


FIGURE 6.5d
TYPICAL OPERATION TESTING
VEHICLE ROAD LOAD POWER VS BATTERY POWER
TEST SEGMENT 4

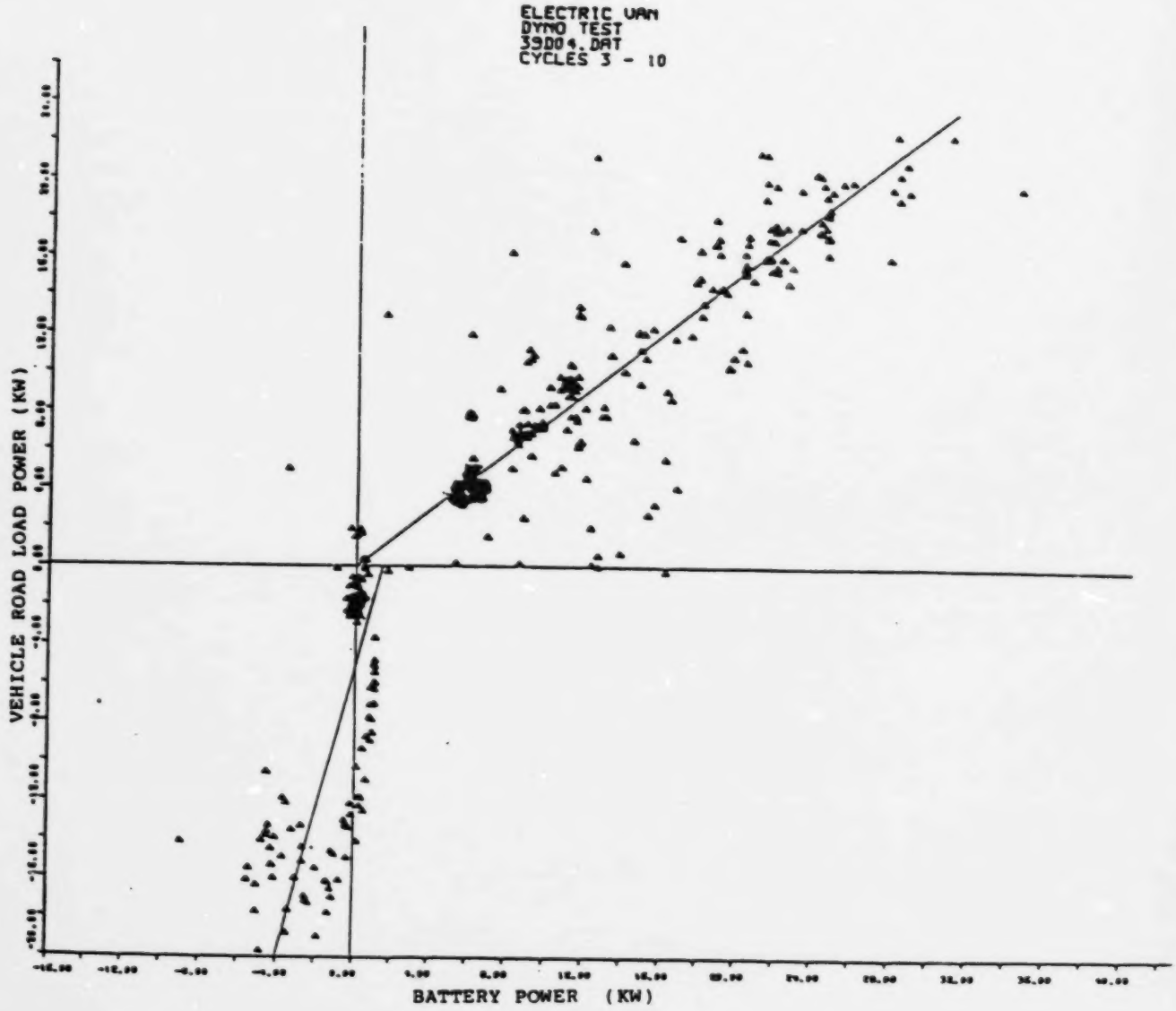
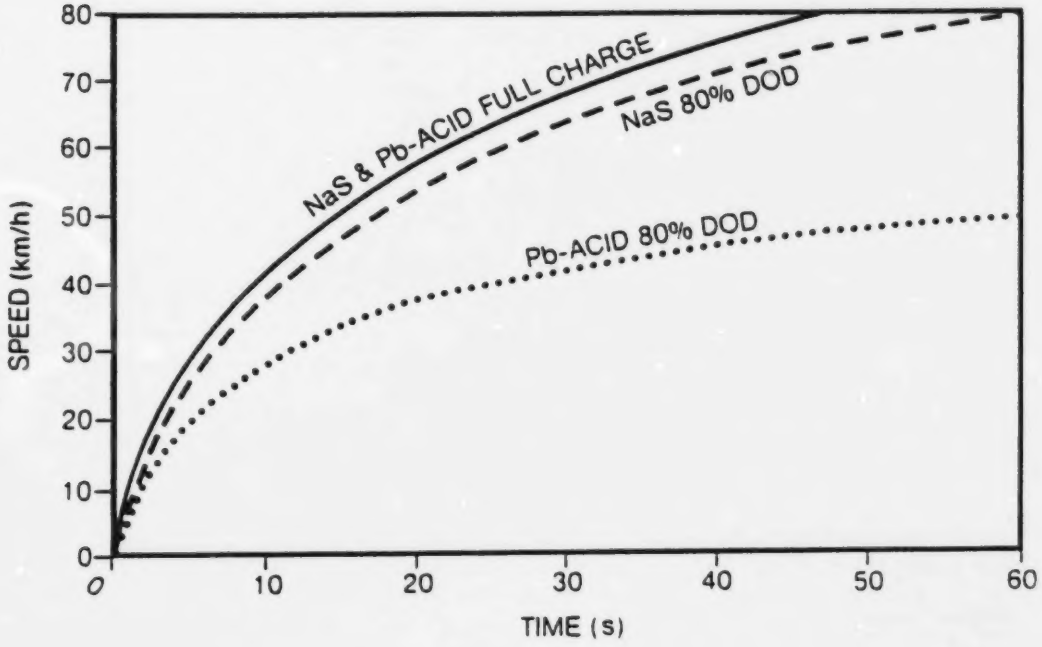


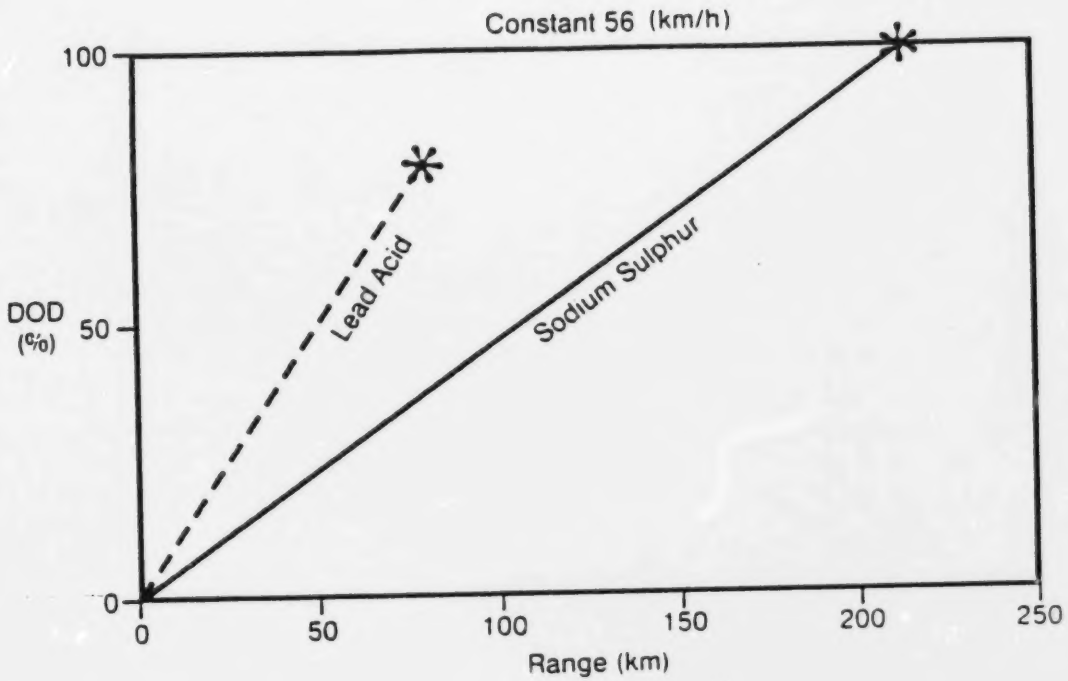
FIGURE 6.5e

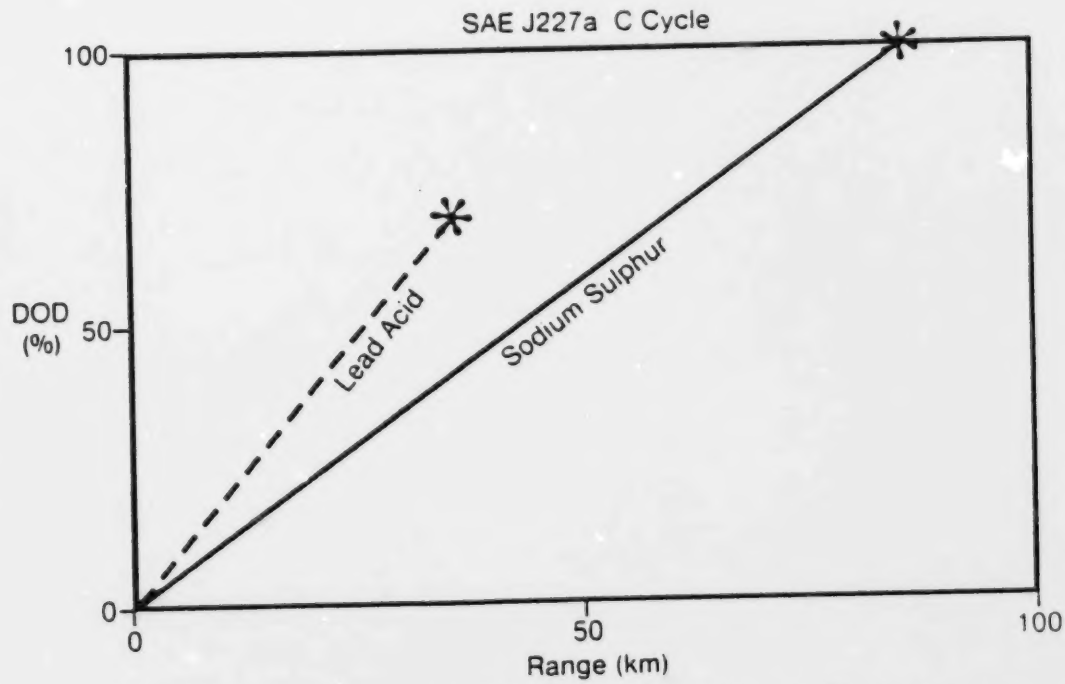
DYNAMOMETER TESTING
VEHICLE ROAD LOAD POWER VS BATTERY POWER
LINES OF BEST FIT
39D04.DAT



Vehicle Acceleration at Full Charge and 80% Depth of Discharge

FIGURE 8.1





Vehicle Range Versus Depth of Discharge

*Failure to meet Test Criteria

FIGURE 8.2

APPENDIX V

INSTRUMENTATION

The transducers and equipment used by MTC consisted of the following items:

1/ Vehicle Speed
Nucleus NC8, Precision Fifth Wheel
Frequency/Voltage Converter, Made by MTC

2/ Battery Input and Output Charge
OHIO Semitronics, Inc., AH72-400 Ampere-Hour Meter

3/ Battery Input and Output Power and Energy
OHIO Semitronics, Inc., WH 72-37 Watt-Hour Meter

4/ Battery Output Voltage
Voltage Divider, Made by MTC

5/ Motor Armature Current
OHIO Semitronics, Inc., CT 400L Hall Effect Current Probe

6/ Motor Armature Voltage
Voltage Divider, Made by MTC

7/ AC Energy Consumption
AC Kilowatt-Hour Meter, Provided by Ontario Hydro

8/ 120 V, 60-Cycle Power Supply
12 V dc/12 V ac Inverter

9/ Data Recording - Tape
Six Channel Metraplex FM Multiplexing Tape Recorder Set

10/ Data Recording - Chart
Eight Channel MFE Chart Recorder

TEST INSTRUMENTATION AND CALIBRATION BY DAVIS ENGINEERING

The vehicle was instrumented with the DAVIS Model 359 data acquisition system which was modified to provide 1 Hz sampling rate and 256 KB memory. The following sensors were installed in the vehicle and interfaced to the DAS.

i) Time: calendar time and time from start of test run - on board clock.

ii) Speed, Distance and Acceleration: magnetic pick-up in speedometer cable. Ford Type DT-16F.

iii) Ambient Temperature: temperature probe - analog devices Ac 2626.

iv) Battery Voltage: using voltage divider and 1 Hz filter (see Figure IV attached).

v) Battery Output Current: 50 mV shunt with optical isolation circuit and 1 Hz filter.

The shunt was put in the 108 V battery cable which ranges from minus 180 V to minus 50 V depending on what mode its controller is in. The +50 mV signal cannot be measured directly with good accuracy in the presence of such high common mode voltages so it was necessary to optically isolate the signal. The circuit shown in Figure IV first converts this +50 mV signal to a frequency from 0 to 8 kilohertz, then runs it through an optocoupler with at least 300 V of isolation, to a frequency to voltage converter which provides a filtered 0 to 5 V analog signal to the A/D.

vi) Drive Wheel Torque (both drive wheels): Himmelstein Model MCRT-2782TA 5000 in-lb non contact wheel torque meters with speed pick-up and Model 66010 Universal strain gauge amplifiers (for dynamometer tests).

vii) Dynamometer Torque: interface to dynamometer.

viii) Dynamometer Front Roll Speed: interface to dynamometer.

A calibration check of all sensors was performed prior to testing and periodically during the test program.

CURRENT + VOLTAGE MEASUREMENT CIRCUITS 12/2/86

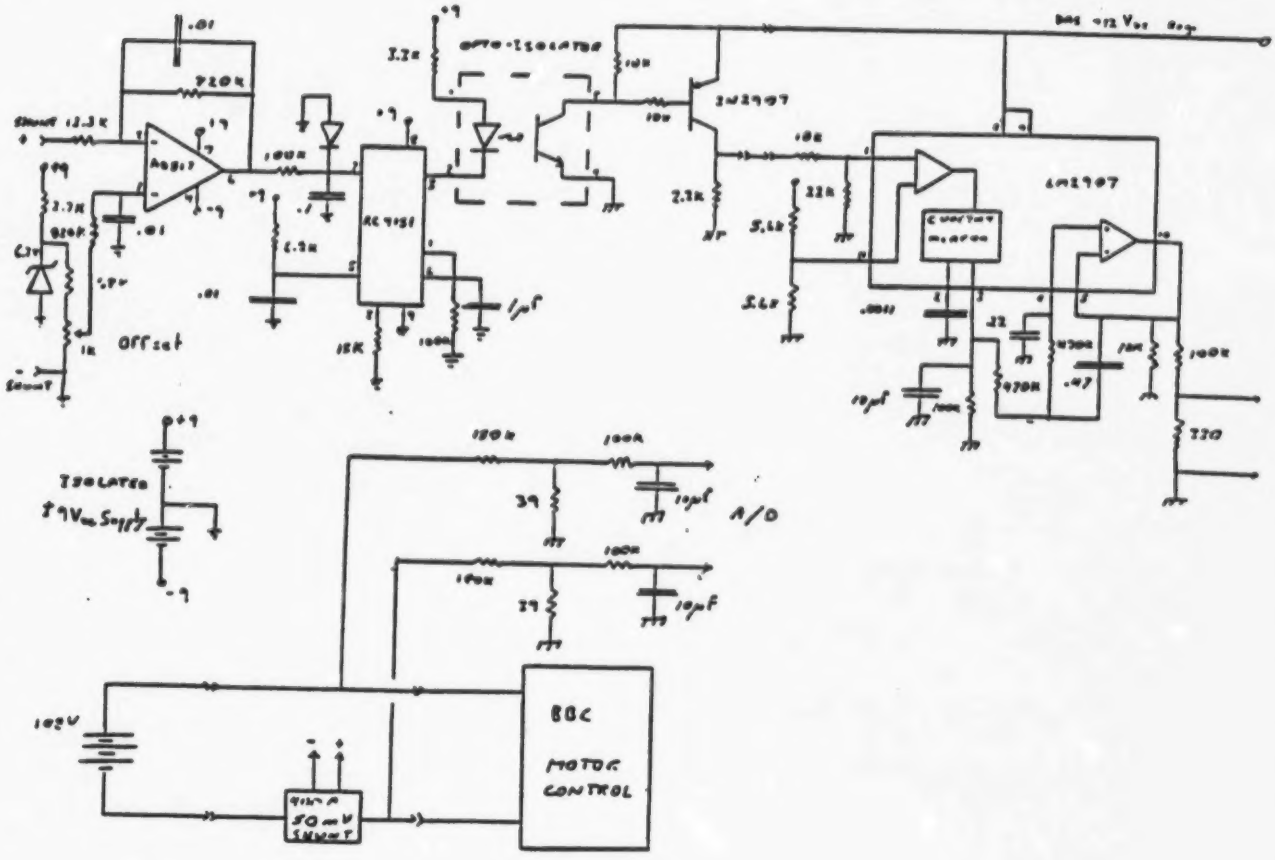


FIGURE IV
INSTRUMENTATION VOLTAGE DIVIDER
(DAVIS ENGINEERING LTD.)

APPENDIX VIa

EV01 OPERATING PROBLEMS

Date	Odometer km	Sympton	Fault	Fixed By
06 85		Would not start	Auxiliary battery	Replaced
09 86	5500	Charger malfunction	Charger	Powerplex Replaced charger Sent defective unit to BBC for repair
18 11 86		Repaired, original charger was reinstalled		

APPENDIX VIb

EV02 OPERATING PROBLEMS

Date	Odometer km	Sympton	Fault	Fixed By
13 09 85	3212	Greenish liquid discharged at the ventilation tube	Thermo-management circuit leaked.	Powerplex
17 09 85	3283	Main line fuse blown out twice	Controller	Powerplex
04 10 85	3433	Acceleration rate and motor current were reduced	Connection between the acceleration cable and controller was loosened	Powerplex
13 12 85	N/A	N/A	Controller malfunction	BBC
26 06 86	6084	Vehicle stalled	Bad contact between the ground lead for the ac plug and the control circuit	Powerplex
23 07 86	6174	Warning signs on during charging and discharging times	Censor connector became loosened	Powerplex
24 07 86	6212	Vehicle stalled	Bad contact at the auxiliary battery ground wire	Powerplex
11 86	6900	The charger was taken out from EV02 and was installed on EV01		
18 11 86	7124	Charger turns on and off repeatedly	Charger malfunction	The original EV02 charger was removed from EV01 and was installed back on EV02 by Powerplex
		The EV01 charger was repaired by BBC		
02 01 87	7489	The cooling fan did not work	Fan power cable in the controller was overheated	Powerplex

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(1) Ontario Ministry of Transportation and Communications, "BBC/Chrysler Electric Vehicle Quarterly Report - Progress Report No. 1", September 30, 1985.

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(4) Powerplex Technologies Inc., "An Electric Drive System for the Chrysler T115 Van, 8th Electric Vehicle Symposium", Washington 1986.

(5) IBI Group, "Electric Van Market Update Study", Toronto, June 27, 1985.

(6) Stegor Consultants Ltd., "Power Battery Development Study", Cambridge, February 1985.

(7) University of Waterloo - Faculty of Engineering - W. C. Edwards, "A Comparison of Batteries for Electric Vehicles", Waterloo, June 2, 1986.

(8) B. D. McNicol and D.A.J. Rand, "Power Sources for Electric Vehicles", Elsevier Science Publishers, 1984.